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Investigation of Transport Airplane Fuselage Fuel Tank Installations Under Crash Conditions

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Final Report

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16. Abstract

This report describes the initial follow-on effort to a recently concluded study described in "Fuel Containment Concepts - Transport Category Airplanes" (reference 1), which concluded that a short term test program involving fuselage mounted fuel tank installations be conducted.

The three contemporary fuel tank installation configurations investigated in this study include:

- Conformable tank containing a bladder and supported within a dedicated structure,
- Double wall cylindrical strap in auxiliary tank, and
- Bladder cells fitted in the lower fuselage.

This report reviews existing crash design criteria, as well as current proposals which could affect fuel tank installations. Program KRASH was used to help evaluate the performance of a fuselage mounted tank when subjected to dynamic loads. A total of 21 cases were analyzed, including 12 vertical impacts and 9 longitudinal pulse conditions and/or configurations. The analytical models included 120-inch sections, 300-inch segments and full airplane representations. Results in the form of floor and fuel tank accelerations, floor and fuel tank attachment loads and fuselage crush were obtained.

Two test conditions are proposed to represent conditions that best meet the crash design criteria developed in a previous FAA sponsored parametric study, reference 2, as well as to recognize realistic structures and tests that can be run. A preliminary test plan is included.

17. Key Words (Suggested by Author(s))
fuel containment, dynamic response, vertical impact, longitudinal pulse, analysis, KRASH, crash design criteria, fuselage crush

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FOREWORD

This report was prepared by the Lockheed Aeronautical Systems Company, under contract DTFA03-86-C-00005, sponsored by the Federal Aviation Administration Technical Center. This report describes the Task Area II, Task Order No. 1, assessment of fuselage mounted fuel tank installations in a crash environment. The work was administered under the direction of R. Johnson of the Federal Aviation Administration (FAA).

The Lockheed Aeronautical Systems Company effort was performed within the Flutter and Dynamics Department.

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EXECUTIVE SUMMARY

The reference 1 report reviewed the state of the art in crashworthy fuel tank systems for transport airplanes. The reference report included a review and evaluation of the crash environment and crash design criteria. A benefit-to-cost analysis was performed which prioritized fuselage mounted fuel tank installations as the most viable short-term approach.

This report evaluates the following three contemporary fuselage fuel tank installations with regard to performance in a dynamic crash environment:

- Conformable tank containing a bladder and supported within a dedicated structure.
- Double wall cylindrical strap in auxiliary tank.
- Bladder cells fitted in the lower fuselage.

Existing and current proposals related to crash design criteria are evaluated and compared. Included is the recently released FAA Seat Improvement Final Rule (reference 3). The three aforementioned fuel tank installation concepts are examined with regard to their crash resistant features, design philosophies and loading paths. Program KRASH was used to help determine anticipated structural responses for the different fuselage mounted concepts during the course of a crash event. A total of 21 KRASH analytical computer runs (12 vertical-impacts and 9-longitudinal pulses) were made. The results in the form of floor and floor tank accelerations, floor and fuel tank attachment loads, fuel tank displacement and underfloor crash were obtained, evaluated and summarized.

Taking into consideration the current analysis results, the recently completed parameter study (reference 2) and longitudinal section test results (reference 4), as well as previously conducted full-scale airplane tests, it was concluded that two fuselage section tests should be initially performed. A preliminary test plan for two such tests are included in Appendix A and the test parameters are described as follows:

1. <u>Vertical Impact</u>

• Frame fuselage section length:	120 inches
• Impact Velocity of:	20 to 25 ft./sec.
• Rise time to peak:	0.075 seconds *
• Peak acceleration:	Floor of 8 to 10 g *
• Weight:	8500 to 10,000 pounds
• Fuel tank configuration:	One double-wall cylindrical tank, passenger floor mounted

* Parameters resulting from impact velocity

2. <u>Longitudinal Impact</u>

• Frame fuselage section length:	120 inches
• Impact velocity:	30 to 36 ft./sec.
• Rise time to peak:	0.07 to 0.10 sec.
• Peak acceleration:	10 to 14.2 g
• Specimen weight:	8500 to 10,000 pounds
• Fuel tank configuration:	One double-wall cylindrical tank, passenger floor mounted

SECTION 1

INTRODUCTION

A four phase study to identify potential fuel containment concepts for transport category airplanes is described in reference 1. The reference 1 report included a comprehensive review and evaluation of:

- Crash environment (accident, crash test, and analyses data)
- Design: guidelines, specifications, criteria, and procedures
- State-of-the-art technology status
- Design concepts and recommendations
- Benefit/cost trade-offs

Figure 1-1 depicts the approach which led to the development of the reference 1 prioritized fuel containment concepts. Several design concepts were assigned potential benefits (annualized fatality reduction) and penalties (annualized weight and costs). The concepts were ranked according to a penalty to benefit ratio which was established and referred to as an "effectiveness" ratio. A summary of the estimates of weight penalty versus fatality reduction is shown in table 1-1. The lowest ratio denotes the concept potentially most effective in reducing fire fatalities. However, the concept termed most effective does not necessarily provide the potential to achieve the greatest fire fatality reduction. The results of the reference 1 study concluded that a Crash Resistant Fuel System (CRFS) for fuselage auxiliary fuel tanks would be most effective while Wing Span Structural Modifications would be least effective. The reference 1 study recommendations included a near-term (1-3 year) and long-term (3-10 year) Research and Development (R&D) program, as depicted in figure 1-2.

This report concentrates on the near-term goals of determining the need to incorporate a CRFS for fuselage auxiliary fuel tanks. To make this determination, it is necessary to perform the following tasks:

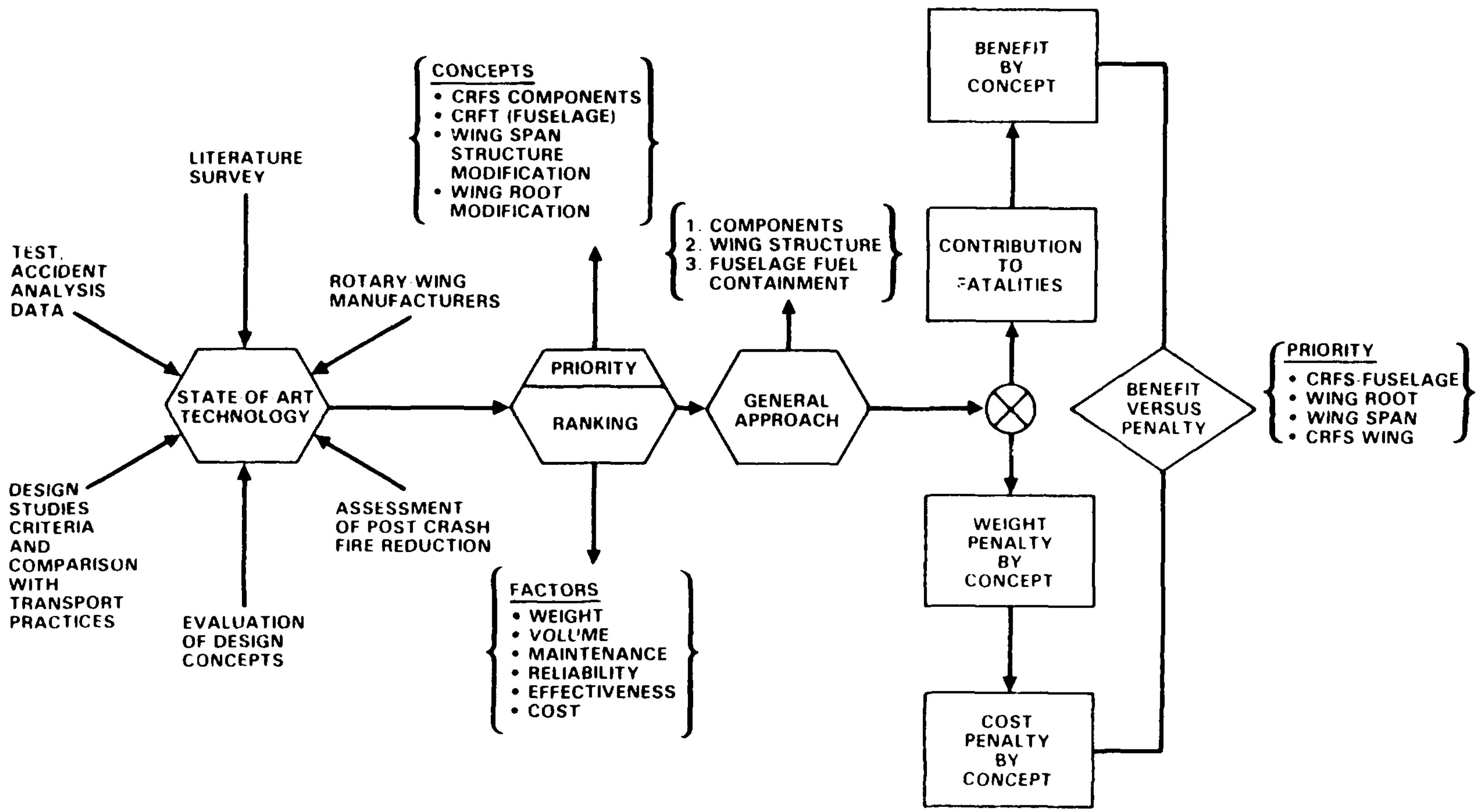


Figure 1-1. Development of Prioritized Fuel Containment Concepts

TABLE 1-1. PENALTY VERSUS POTENTIAL FATALITY REDUCTION

CONCEPT (COST FACTOR)	PER ANNUM			RATIO OF FLEET PENALTY TO FATALITY REDUCTION	
	PENALTY**				
	FLEET* WEIGHT LB x 10^6	FLEET* COST x 10^6	FATALITY REDUCTION POTENTIAL	WEIGHT x 10^6	COST x 10^6
WING ROOT MODIFICATIONS					
A. STRUCTURAL CHANGE (1.5)	0.54	0.82	15.5	0.035	0.053
B. CENTERSECTION CRFS (1.0)	0.66	0.66	10.0	0.066	0.066
C. (A + B)	1.28	1.47	25.5	0.050	0.058
WING SPAN MODIFICATION (1.5) AND CRFS	1.57	2.35	21.6	0.072	0.109
CRFS FUSEL. AUX. TANKS (1.0)	0.83	0.83	24.0	0.035	0.035
CRFS — ALL	3.06	3.84	55.6	0.055	0.069
WING ROOT MODIFICATION AND CRFS	2.32	2.30	49.5	0.047	0.047

*BASED ON 3500 AIRPLANES OVER 10 YEAR PERIOD. USE 350 AIRPLANES PER ANNUM.
**PENALTIES BASED ON RESIZED AIRPLANE.

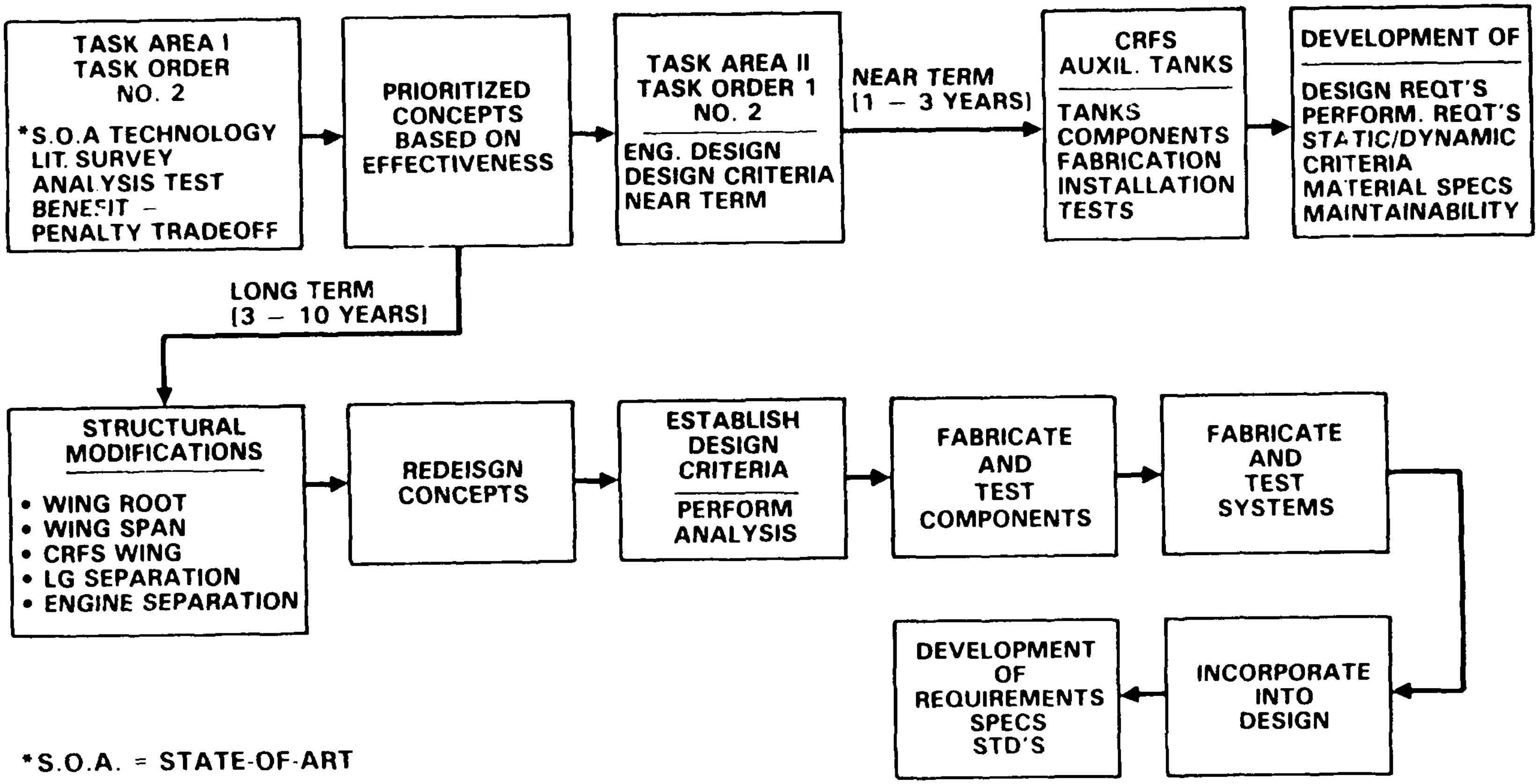


Figure 1-2. Task Area I, Task Order No. 1 Recommendations

- Define applicable crash design criteria.

- Analyze auxiliary fuel tank concepts and installations with regard to existing or potential crash design criteria.

- Determine level of compatibility between existing designs/installations and crash design requirements.

- Establish test configurations, conditions and measurement parameters needed to evaluate designs/installations.

The definition of the crash design criteria was derived from an evaluation of existing criteria (references 5, 6, 7, and 8), as well as recently amended criteria (reference 3) and studies that could affect design and compliance requirements (references 2, 4, and 9-11). The fuselage tank installation concepts reviewed in the reference 1 effort included:

- Conformable tank containing a bladder and supported within a dedicated structure.

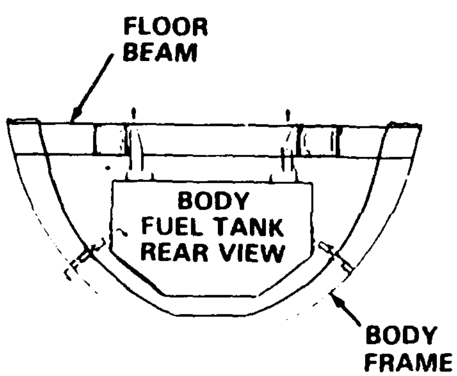
- Double-wall cylindrical strap-in auxiliary tank.

- Bladder cells fitted in the lower fuselage.

The crash resistant features and potential improvements of each concept are presented in figures 1-3, 1-4, and 1-5, respectively.

These designs/installations are analyzed with regard to load capability for existing or potentially future design criteria. If new criteria is applicable, it may be necessary to evaluate fuel tank installation on the basis of compliance to a specified test condition.

TANK INSTALLATION



CRASH RESISTANT FEATURES

- THE LOCATION PROVIDES ADEQUATE CRASH DISTANCE ABOVE THE FUSELAGE LOWER SKIN AND AVOIDS PLACEMENT IN THE FUSELAGE WHERE BREAKS TYPICALLY OCCUR
- THERE IS SEPARATION FROM THE PASSENGER COMPARTMENT
- THE USE OF BLADDER CELLS WITHIN DEDICATED STRUCTURE PROVIDED ADDED PROTECTION FROM PUNCTURE
- THE DESIGNS ALLOW FOR TANK DISPLACEMENT TO MINIMIZE OR REDUCE FUEL LINE BREAKAGE
- DESIGN TO MEET, OR EXCEED, FAR REQUIREMENTS
- THE SEPARATELY CONTAINED CELLS ARE DESIGNED TO REACT CRASH LOADS VIA PREDETERMINED LOAD-PATH CONSIDERATIONS

POTENTIAL IMPROVEMENTS

- THE USE OF SELF-SEALING BREAKAWAY FITTINGS TO ENSURE THAT FUEL SPILLAGE IS MINIMIZED IN THE EVENT OF LARGE
- USE OF A MORE TEAR RESISTANT BLADDER MATERIAL

Figure 1-3. Bladder Supported Within a Dedicated Structured Box

TANK INSTALLATION	CRASH RESISTANT FEATURES	POTENTIAL IMPROVEMENTS
	• LOCATED IN REGION WHERE ADEQUATE FUSELAGE CRUSH IS ANTICIPATED AND AWAY FROM BREAK/SEPARATION REGIONS • RELATIVELY SMALL AMOUNT OF FUEL (160 TO 440 GALLONS MAXIMUM) IS SPILLED, IF A SINGLE TANK RUPTURES	• RELOCATION OF INTERCONNECTING LINES FROM BELOW THE TANKS e.g., PLUMBING SHOULD BE MOVED FROM EXTERNAL AND BELOW THE TANK TO INTERNAL AND ABOVE, WHERE POSSIBLE • USE OF FLEXIBLE LINES, BREAK-AWAY FITTINGS • ADDITION OF REDUNDANT SUPPORT STRUCTURE TO PREVENT TANKS FROM BREAKING FREE IF THE FUSELAGE EXPERIENCES EXTENSIVE DAMAGE

Figure 1-4. Double-Wall Cylindrical Strap-In Auxiliary Tanks

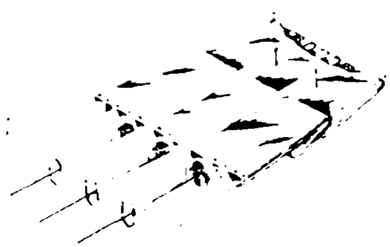
TANK INSTALLATION	CRASH RESISTANT FEATURES	POTENTIAL IMPROVEMENTS
BLADDER CELLS FITTED IN THE LOWER FUSELAGE 	• THE CELL IS LOCATED BELOW THE WING BETWEEN THE FRONT AND REAR SPARS OF THE WING CARRY-THROUGH STRUCTURE, THUS AVOIDING A LIKELY FUSELAGE BREAK LOCATION.	• THE BLADDER MATERIAL USED IS MKF6396. A MORE TEAR/CRASH RESISTANT MATERIAL SHOULD PROVIDE ADDITIONAL PROTECTION.
	• BULKHEADS AND BEAMS PROVIDE STIFFNESS AND CRASH SUPPORT IN THE EVENT OF AN IMPACT IN WHICH THE MID-FUSELAGE LOWER SURFACE MAKES CONTACT WITH THE GROUND (I.E., GEARS RETRACTED).	• USE OF SANDWICH CONSTRUCTION OR EQUIVALENT DESIGN BETWEEN THE TANK CELL AND THE LOWER FUSELAGE SKIN BELOW WOULD AFFORD ENERGY-ABSORBING CRUSHABLE STRUCTURE IN A REGION WHERE IMPACT WITH THE GROUND COULD OCCUR.
	• FUEL SYSTEM COMPONENTS ARE WITHIN THE CELL AND LOCATED AWAY FROM THE MOST VULNERABLE SURFACE DURING A CRASH IMPACT.	• FLEXIBLE LINES, BREAK-AWAY FITTINGS
	• THE USE OF A BLADDER REDUCES THE LIKELIHOOD OF A MASSIVE LEAK, WHICH REDUCES THE CHANCES OF FUEL REACHING AN IGNITION POINT AND ALSO PROVIDES MORE EGRESS TIME.	

Figure 1-5. Bladder Cells Fitted in the Lower Fuselage

SECTION 2

CRASH DESIGN CRITERIA

2.1 EXISTING CRITERIA

Current design criteria which pertains to fuel tanks/cells and systems is contained in several documents including references 3 and 5-8. For example, in the Federal Airworthiness Requirements (FAR 25, reference 5) design load factors are given in paragraph 25.561 which states:

25.561 General

(a) The airplane, although it may be damaged in emergency landing conditions on land or water, must be designed as prescribed in this section to protect each occupant under those conditions.

(b) The structure must be designed to give each occupant every reasonable chance of escaping serious injury in a minor crash landing when -

(1) Proper use is made of seats, belts, and all other safety design provisions;

(2) The wheels are retracted (where applicable); and

(3) The occupant experiences the following ultimate inertia forces acting separately relative to the surrounding structure:

(i) Upward - 2.0 g

(ii) Forward - 9.0 g

(iii) Sideward - 1.5 g

(iv) Downward - 4.5 g, or any lesser force that will not be executed when the airplane absorbs the landing loads resulting from impact with an ultimate descent velocity of five f.p.s. at design landing weight.

(c) The supporting structure must be designed to restrain, under all loads up to those specified in paragraph (b) (3) of this section, each item of mass that could injure an occupant if it came loose in a minor crash landing.

Section 25.721 discusses the prevention of fuel spillage of sufficient magnitude to cause a fire hazard due to the failure of a) the main landing gear system or b) structural component failures during a controlled landing with one or more landing gear legs not extended. This section states:

25.721 General

(a) The main landing gear system must be designed so that if it fails due to overloads during takeoff and landing (assuming the overload to act in the upward and aft directions), the failure mode is not likely to cause -

(1) For airplanes that have passenger seating configuration, excluding pilots seats, or nine seats or less, the spillage of enough fuel from any fuel system in the fuselage to constitute a fire hazard; and

(2) For airplanes that have a passenger seating configuration, excluding pilots seats, of 10 seats or more, the spillage of enough fuel from any part of the fuel system to constitute a fire hazard.

(b) Each airplane that has a passenger seating configuration excluding pilots seats, of 10 seats or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.

(c) Compliance with the provisions of this section may be shown by analysis or tests, or both.

Other sections of FAR 25 which are applicable to the prevention of fuel spillage and a subsequent fire hazard are:

- 25.855 Cargo and Baggage
- 25.863 Flammable Fluid Fire Protection
- 25.954 Fuel System Lightening Protection
- 25.963 Fuel Tanks; General
- 25.967 Fuel Tank Installation
- 25.971 Fuel Tank Sump
- 25.973 Fuel Tank Filler Connection
- 25.975 Fuel Tank Vents and Carburetor Vapor Vents
- 25.977 Fuel Tank Outlet
- 25.981 Fuel Tank Temperature

- 25.991 Fuel Pumps
- 25.993 Fuel System Lines and Fittings
- 25.1359 Electrical System Fire and Smoke Protection

Applicable FAR 121 (reference 6) sections include:

- 121.227 Pressure Cross Feed Arrangements
- 121.229 Location of Fuel Tanks

The British Civil Airworthiness Requirements (BCAR, reference 7) contain in sub-section D3-Structures. Chapter (D3-9) on Emergency Alighting Conditions which reads as follows:

1. GENERAL - The requirements of this chapter are intended to ensure that in the event of an aeroplane making an emergency landing involving accelerations up to prescribed maxima, the safety of the occupants has been fully considered. Such consideration extends to the avoidance of injury to the occupants due to the damage which the aeroplane is likely to suffer under the prescribed conditions.

   Note: Hazards to occupants in crash conditions can be reduced by designing the airplane so that the following occurrences are unlikely to cause either direct physical injury to the occupants or injury as a result of rupture of the tanks --

   4 g downwards to 4.5 g upwards
   9 g forwards to 1.5 g rearwards
   zero to 2.25 g sideways

2. (Not Applicable)

3. EQUIPMENT - Items of equipment shall, so far as is practicable, be positioned so that if they break loose they are unlikely to cause injury to the occupants or to nullify any of the escape facilities provided for use after an emergency alighting. When such positioning is not practicable the attachment and surrounding structure shall be designed to withstand inertia forces at least equal to those prescribed in 1.

4. CONDITIONS

   a. Crash Landing. The design of the aeroplane shall be such that there will be every reasonable probability of the occupants escaping serious injury in the event of a crash landing, including the case of wheels retracted when such contingency is possible.

b. Turnover. - The structure of the aeroplane shall be designed to protect the occupants in the event of a complete turnover, unless the configuration of the aeroplane renders such a contingency extremely improbable.

AC 25-8 "Auxiliary Fuel System Installations" (reference 8) addresses several areas pertinent to crashworthiness. The intent of the circular is to be directed to modifications to existing fuel systems and particularly those associated with smaller FAR 25 airplanes. However, much of the contents are appropriate for all FAR 25 airplanes. The advisory circular contains material arranged in six chapters as follows:

1. Fuel System Installation Integrity and Crashworthiness
2. Auxiliary Fuel System Arrangement
3. Component Materials
4. Auxiliary Fuel System Performance
5. Impact of System on Airplane Operation and Performance
6. User Installation Requirements

The material contained in Chapters 1 and 2 is most relevant to this current study.

A more detailed description of the material contained in references 5-8 is provided in reference 1.

2.2 IMPROVED SEAT SAFETY STANDARDS, FINAL RULE

In May of 1988 the Department of Transportation (DOT), Federal Aviation Administration (FAA) issued a final rule for improved seat standards (reference 3). The rule provides revised static loads which are applicable to all mass items and introduces dynamic testing for seats. The following is a summary of the rule with regard to FAR 25 (reference 5) affected mass items which could be pertinent to fuel containment.

1. Amend paragraph 25.561 by revising paragraphs (b)(3)(i), (iii) and (iv), and add new paragraph (b)(3)(v) as follows:

25.561 General

*   *   *   *   *
(b) * * *
(3) * * *
(i) Upward - 3.0 g
*   *   *   *   *
(iii) Sideward - 3.0 g
(iv) Downward - 6.0 g
(v) Rearward - 1.5 g
*   *   *   *   *

2.3 ANALYTICALLY DEVELOPED CRASH DESIGN ENVELOPE

The crash design velocity envelope for floor mounted components developed during the KRASH parametric sensitivity study (reference 2) and discussed in the reference 1 report is shown in figure 2-1. The fuselage underside crush distribution considering both test and analyses data is shown in figure 2-2. Based on the data generated in reference 2 the following potential criteria emerges for fuselage installed components mounted supported floor structure and below the passenger floor:

- Fuselage Underside Crush Protection

Forward of Wing Section	:	14 inches
Wing Center Section	:	10 inches
Aft of Wing Section	:	16 inches

- Dynamic Pulse (Triangular Shape)

Vertical - only

Velocity change, ΔV	=	25 ft./sec.
Rise time, t_r	=	0.075 sec.
Peak acceleration,	=	10.4 g

Longitudinal - only

Velocity change, ΔV	=	30 ft./sec.
Rise time, t_r	=	0.10 - 0.09 sec.
Peak acceleration,	=	9.3 - 10.2 g

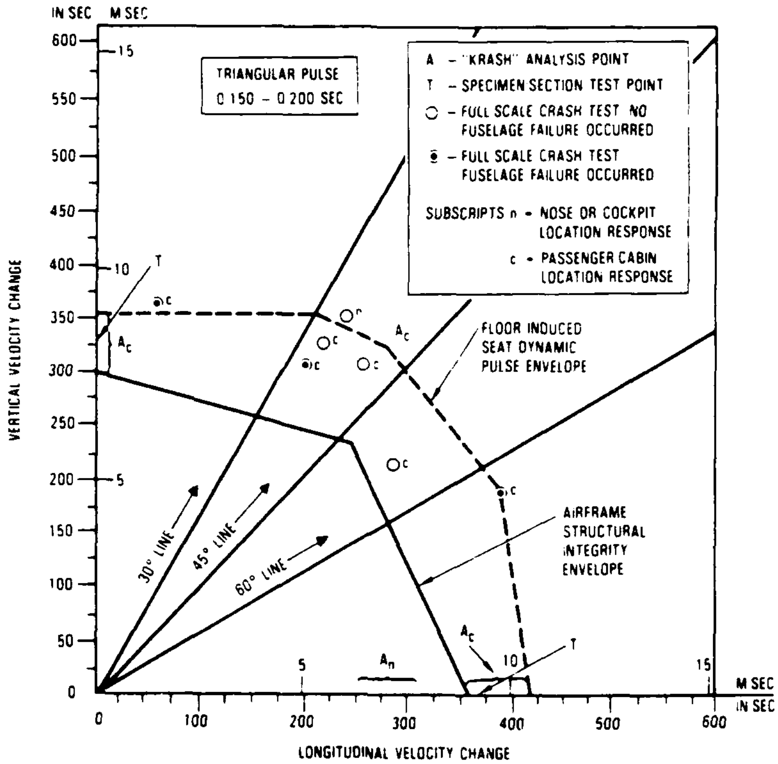


Figure 2-1. Structural Integrity Velocity Envelopes for Transport Category Airplanes

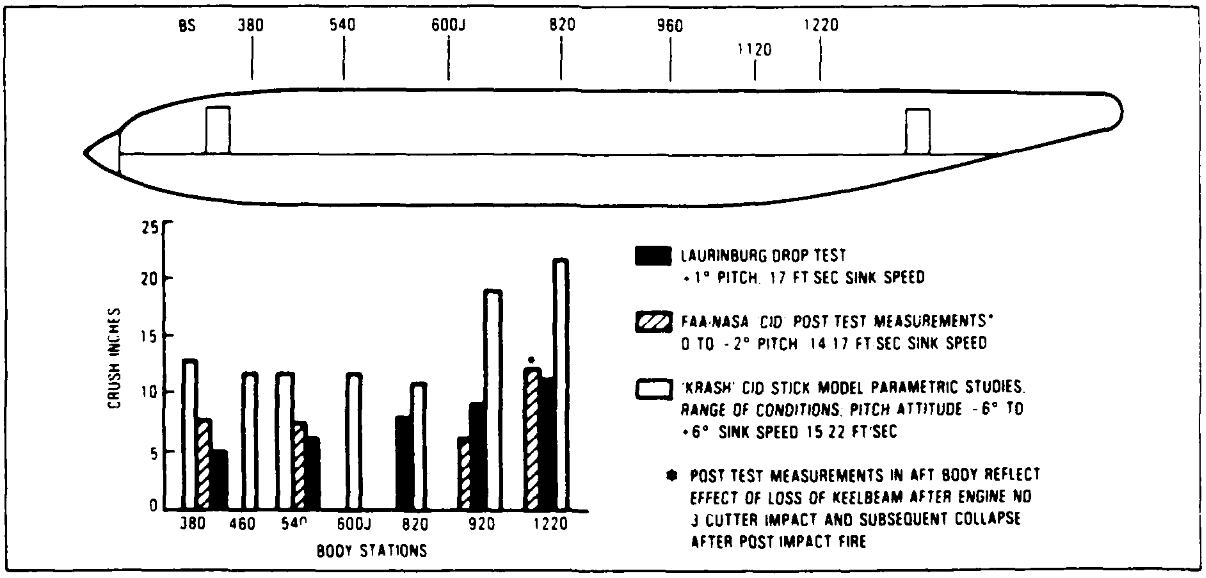


Figure 2-2. Lower Fuselage Underside Crush Distribution

Combined Longitudinal - Vertical

(a) 30 degree pitch nose-down			
Velocity change, ΔV	=	28 ft./sec.	
Rise time, t_r	=	0.075 sec.	Resultant
Peak acceleration,	=	11.5 g	
(b) 45 degree pitch nose-down			
Velocity change, ΔV	=	31 ft./sec.	
Rise time, t_r	=	0.075 sec.	Resultant
Peak acceleration,	=	12.7 g	

SECTION 3

FUSELAGE FUEL TANK INSTALLATIONS

Current commercial airplanes typically carry fuel in the wings. However, in some designs operational requirements dictate the provision of fuel tankage in the fuselage. The fuel that is in the body may be located in the unpressurized area (center wing) or in the pressurized area (e.g., the cargo compartment). Typically, the center wing tank on a transport airplane is also an integral tank but it is isolated from the personnel compartment by a fume-proof and fuel-proof enclosure as required by Federal Aviation Regulations paragraph 25.967. Fuel tanks such as the center wing tank which are located within the body contour are designed to meet the g loads prescribed for emergency landing, FAR 25.561 and 25.963. When fuel is placed in the fuselage it is in closer proximity to the passengers as compared to the wing tank locations. As the accident data indicate, there is a propensity for fuselage lower surface damage in the more severe crashes. The accident data also show that under severe impact conditions the fuselage will normally break at locations of structural discontinuity. Particular attention must be paid to fuselage tank designs to minimize the risk of fuel spillage under these severe crash conditions. The following three contemporary fuselage tank configurations are examined with regard to their crash resistant features:

1. Double-wall cylindrical strap-in auxiliary tanks
2. Bladder-supported within a dedicated structural box
3. Bladder fuel cells fitted in the lower fuselage

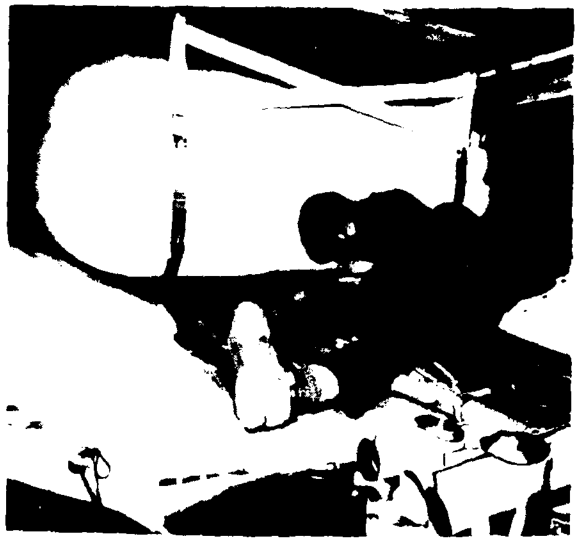
3.1 DOUBLE-WALL CYLINDRICAL STRAP-IN AUXILIARY TANKS

One supplemental fuel system employed by airlines for narrow-body transport airplanes involves the use of quick-mounting, easily removable fuselage fuel tanks. The complete supplemental system consists of double-wall tanks, a cockpit auxiliary fuel panel, a refueling/defueling panel accessible to ground service personnel, fuel lines connecting the supplemental system to the main tanks, and electrical/electronic systems for fuel monitoring and flow control. The tanks are installed in the cargo compartment. They are

structurally supported in cradles attached to the passenger cabin floor or to the cargo floor, as shown in figure 3-1. This approach permits the installation of from one (1) to ten (10) fuel tanks with added capacity of up to a maximum of 2530 gallons, depending on airplane model type. Removability of the tanks also simplifies the maintenance of the lower/inner airframe and/or components within the fuselage center section. No fuel transfer pumps are used. Fuel transfer is accomplished from the cockpit by closing the vent valve, opening the air pressure valve and selecting the appropriate tank. The installed weight ration of the complete supplemental system is 1.0 lb./gal. The system is designed to meet existing FAR 25 crashworthiness criteria.

The tanks vary in size and fuel capacity. Figure 3-2 illustrates two tank sizes. The fore-aft loads acting are based on the 9 g emergency landing condition. The moment imposed by the forward load on each of the components: cradle, tank, and fuel is applied to the floor intercostal. The vertical load is based on the predominant down load, which in many cases is based on gust loading criteria. These loads help size the intercostals to take the auxiliary fuel installation loads. The intercostal design takes into account the number of tanks as well as the number of bays which react the loads. The cradle structure is sized to accommodate the cradle, tank and fuel weights with the appropriate crash load factors. For example, for a 405 gallon tank system shown in figure 3-2 the fore-aft crash load is 9 g X 3235 ~ 29115 lb. and the overturning moment is ~ 734300 in.-lb. The crash load factor for a 5.5 g gust condition is ~ 17792 lb.

Detail load and stress analysis take into account the critical loading conditions based on combinations of tanks and set track loading. The analysis generally considers the intercostals with the seat track upper and lower caps as a continuous beam. Calculations for actual installations indicate that representative narrow-body configuration could exhibit deflections in the order of 0.00001 to 0.0005 inches per unit load (2000 to 10000 lb/in.) at the intercostal locations.



(a) Attached to Passenger Floor

(b) Attached to Cargo Floor

Figure 3-1. Double-Wall Cylindrical Tank Installations

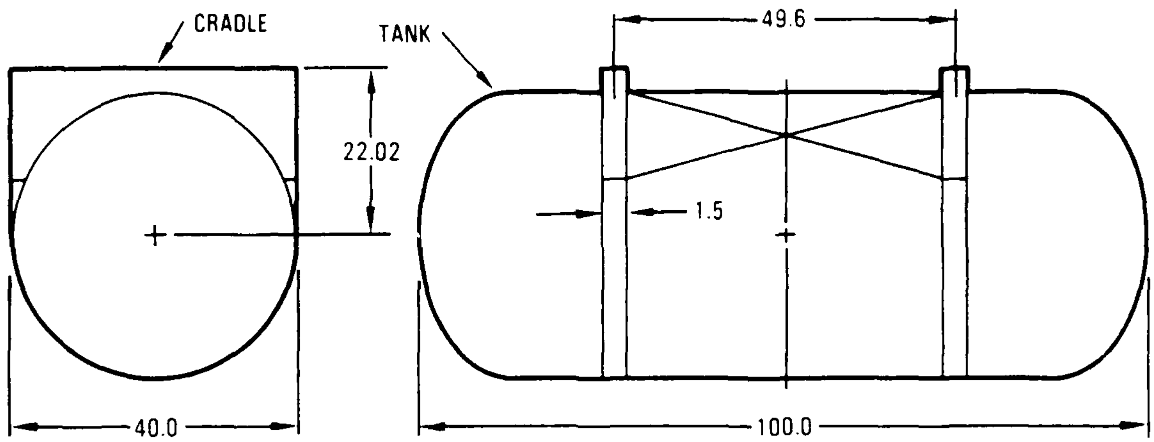
3.1.1 KRASH Analyses

3.1.1.1 Vertical Direction Impact

The analysis of a double-wall cylindrical strap-in auxiliary tank passenger floor deck installation subjected to an impact velocity was performed using program KRASH. Several models were established to evaluate mass responses for different airframe or airplane representations when subjected to an initial vertical impact velocity. Table 3-1 describes the cases analyzed. Figures 3-3, 3-4, and 3-5 show the different KRASH models. Figure 3-3 is used for all the 120-inch, 6-bay representations. Figure 3-4 is used for the 300-inch Section (case 6) and figure 3-5 is the a symmetrical airplane representation (case 7). Table 3-2 shows some of the model size parameters and associated integration and run times. As one can see from table 3-2, the integration interval is higher for the courser model representation and the corresponding run time is reduced, as one might expect. The fuel tanks including associated installation hardware total 4000 pounds each in the models. This weight is higher than the estimated 3335 pounds for a 405 gallon tank as noted in figure 3-2. The KRASH models assume full fuel and the no fuel sloshing occurs. The purpose is to evaluate load transmissability based on relative stiffness between fuel tank attachments and floor structure. The KRASH models do not account for floor stiffening due to added intercostals that may be required to carry the fuel tank loads based on the static load calculations that are normally made for each installation. Added intercostals can account for approximately 52 pounds out of a total of 2733 pounds for a 330 gallon auxiliary fuel tank system. The allowable attachment beam vertical load for these analyses is estimated as 1×10^4 lb. on the following basis: 4000 lb. X 6.5 g = 76000 lb. total; 26000/2 = 13000 lb./side; 1300 lb./2 = 6500 lb./beam; 1.5 factor ~ 10000 lb./beam.

The analysis results for the vertical impact cases are shown in table 3-3. Cases 1 through 5 represent analyses of 6-bay sections which compare relative crush stiffness and the effect of mass. For example, cases 1 and 3 contrast soft frames versus hard points. The peak accelerations are

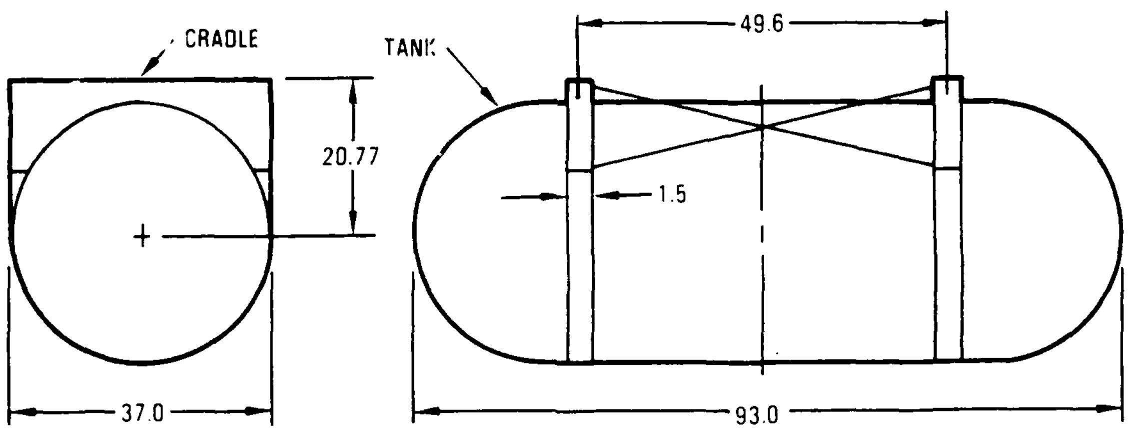
405 GALLON TANK



LOOKING FWD

WEIGHTS	POUNDS
OTHER: (EST)	100
TANK:	302
FUEL:	2876
CRADLE ASSY:	57
	3335

330 GALLON TANK



LOOKING FWD

WEIGHTS	POUNDS
OTHER:	94
TANK:	242
FUEL:	2342
CRADLE ASSY:	54
	2733

OTHER WTS:		POUNDS
	LINES	17
	INTERCOSTAL	52
	MISC	25
		94

Figure 3-2. Two Cylindrical Tank Sizes

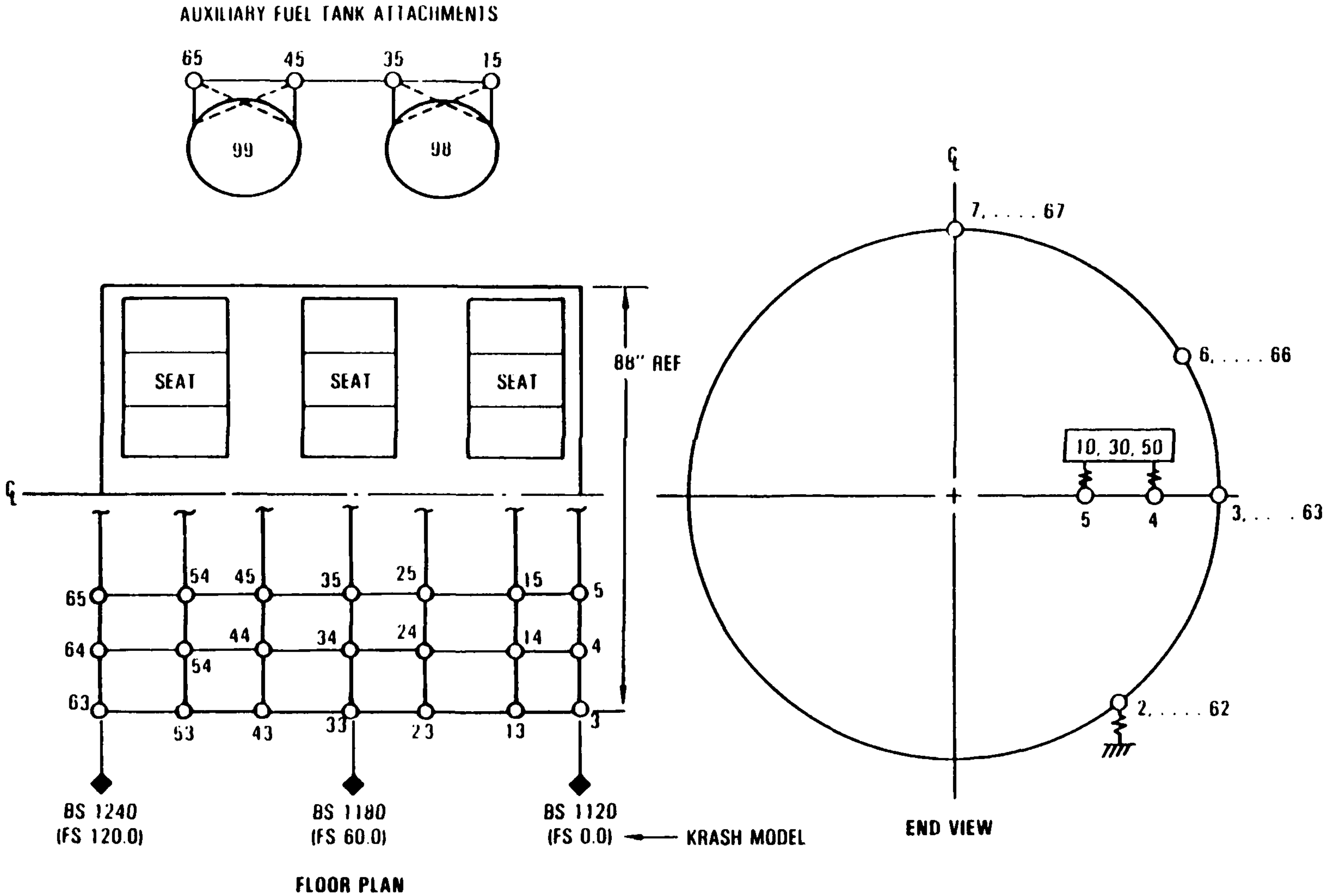


Figure 3-3. Symmetrical 6-bay 120-inch Segment Model Mass Designations

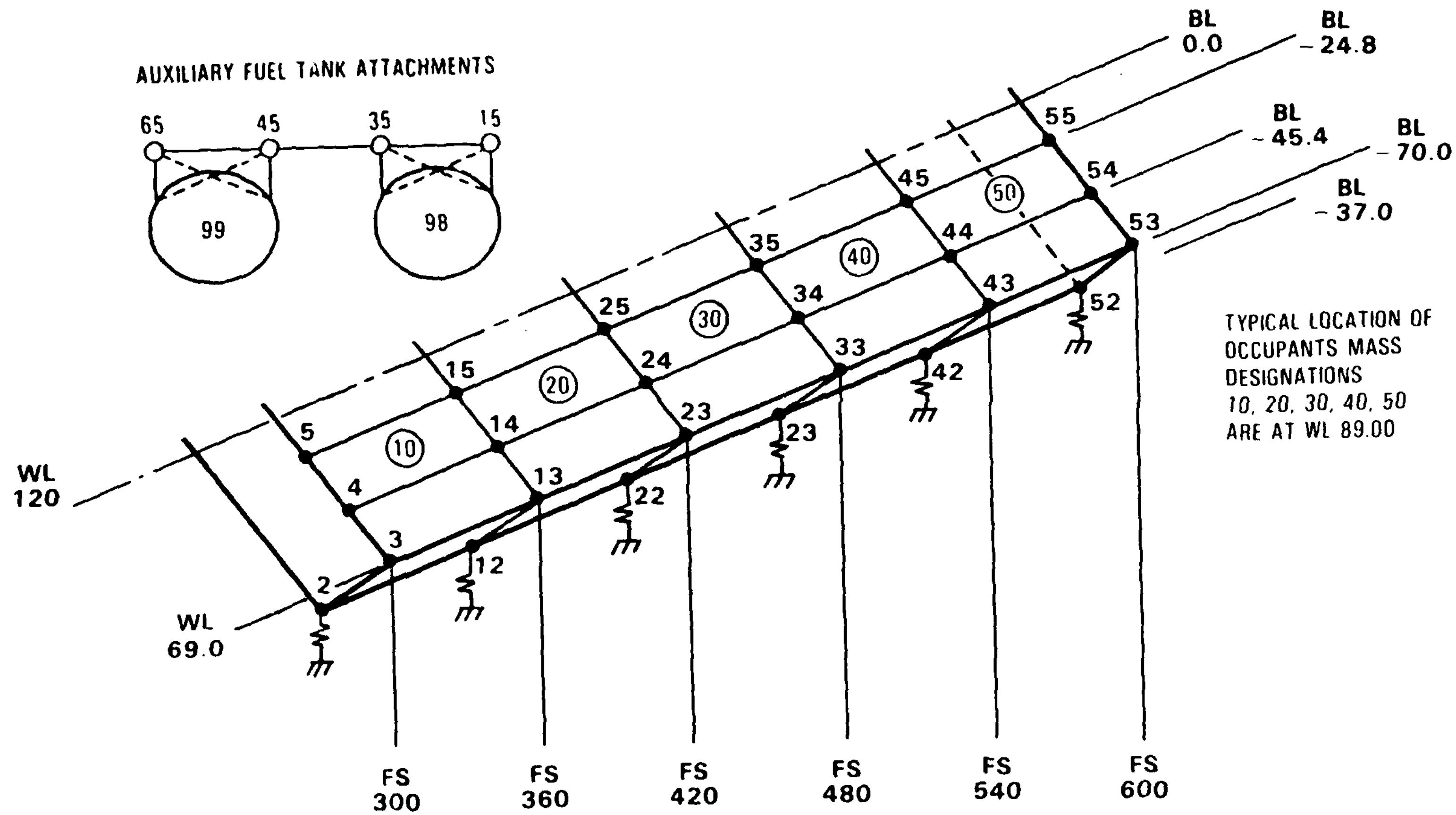


Figure 3-4. 300-inch Symmetrical Section Model

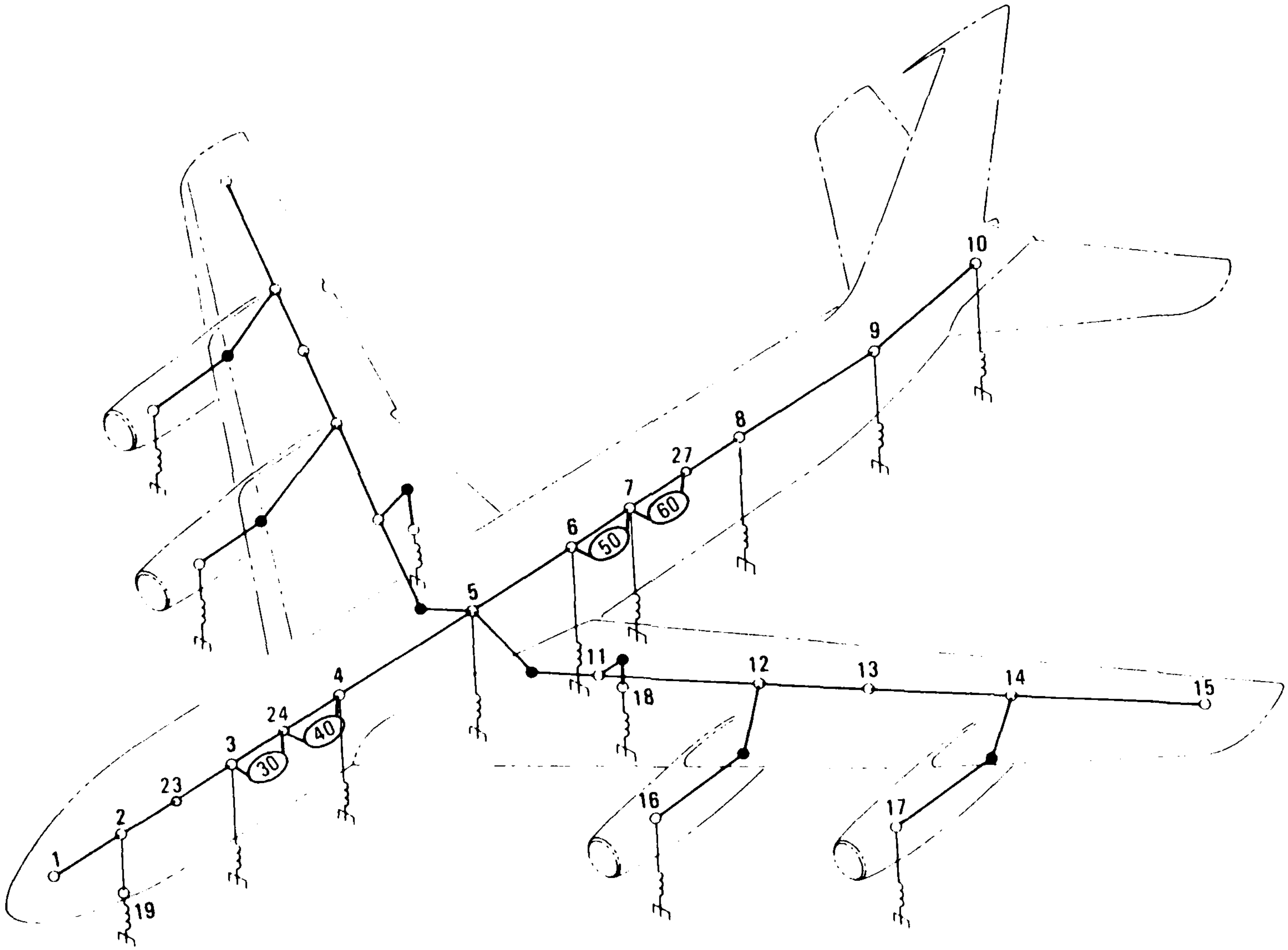


Figure 3-5. Symmetrical Airplane Stick Model

TABLE 3-1. DOUBLE-WALL CYLINDRICAL AUXILIARY FUEL TANK PASSENGER FLOOR MOUNTED ANALYSES CASES (Sheet 1 of 2)

Case No. (Designation)	Weight (lb.)	Vertical Stiffness (lb./in.) x 10^5				Presentation
		Tank-to-Passenger Floor Attachment	Floor Lateral Beams: Outboard - Inboard	Floor Lateral Beams: Inboard - Frame	Floor Longitudinal Beams	
1 (2 ST)	13,690	9.5	1.26	.091	1.5	Soft frame section 6-20-inch bays, 2, tanks, 3 rows of occupants. No hard points, vertical velocity = 25 ft./sec.
2 (2 SX)	10,120	9.5	1.26	.091	1.5	Same as Case No. 1 except no occupant masses
3 (2T)	13,690	5.4	1.26	.091	1.5	Same as Case No. 1, soft intermediate frames and hard points at end locations
4 (2 HT)	36,650	5.4	1.26	.091	1.5	Same as Case No. 3 except added mass at hard point ends
5 (2 WT)	46,250	5.4	1.26	.091	1.5	1-120-inch center section, wing center section crush springs at each end, added mass
6a (2 FS)	16,890	5.4	3.8	.27	.56	1-300-inch segment (60-inch spacing) soft frames, no hard point ends, no added mass, 2 tanks, 3 occupants
6b (2 FS)	16,890	.54	3.8	.27	.56	Same as 6a except lower stiffnesses as noted
6c (2 FX)	16,890	.54	1.26	.091	.56	Same as 6a except lower stiffness as noted

[76]M0849.AB3:1

TABLE 3-1. DOUBLE-WALL CYLINDRICAL AUXILIARY FUEL TANK PASSENGER FLOOR MOUNTED ANALYSES CASES
(Sheet 2 of 2)

Case No. (Designation)	Weight (lb.)	Vertical Stiffness (lb./in.) x 10^5				Presentation
		Floor Lateral Beams				
		Tank-to-Passenger Floor Attachment	Outboard - Inboard	Inboard - Frame	Floor Longitudinal Beams	
7a (Stick 2)	208 000	8.5	NA	NA	20-300	CID airplane stick model - 2 tanks each in fwd. fuselage and aft fuselage - vertical velocity = 22 ft./sec.
7b (Stick 2)	208,000	8.5	NA	NA	20-300	Same as 7a except lower stiffness as noted
7c (Stick 2)	208,000	8.5	NA	NA	20-300	Same as 7a except vertical velocity = 22 ft./sec. and longitudinal velocity = 260 ft./sec. F .5
7d (Stick 2)	208,000	.085	NA	NA	20-300	Same as 7c except lower stiffness as noted

NA = Not Applicable

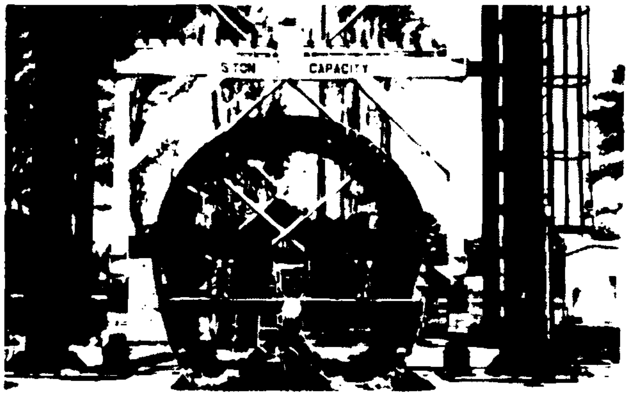
[76]M0849.AB3:2

TABLE 3-2. KRASH MODEL SIZE PARAMETERS

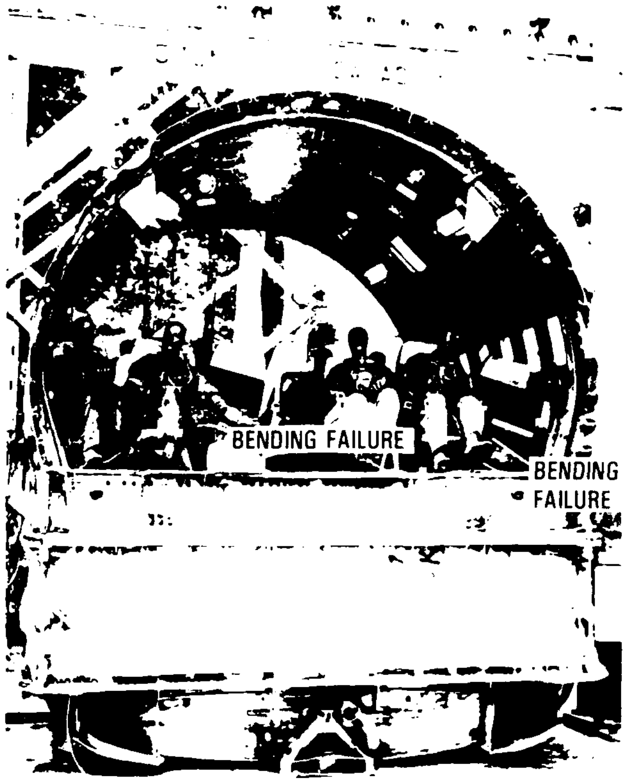
Case No.	Representation	NM	NSP	NB	NNP	NPIN	NUB	Integration Time Interval Sec. x 10^{-6}	Run Time CPU-Sec. per 100 ms.
1	six 20-inch bays	47	7	127	26	30	30	20	432
2	same	44	7	115	26	30	30	20	430
3	same	47	7	127	20	30	26	25	350
4	same	47	7	127	20	30	26	25	350
5	same	47	7	127	26	30	26	20	440
6a/b	five 60-inch bays	43	6	110	26	24	20	50	157
6c	same	43	6	114	26	28	24	50	160
7a/b	symmetrical airplane stick model	24	15	28	26	8	0	100	30
7c/d	same	24	15	36	26	16	8	100	35

NM = Number of Masses
NSP = Number of External Springs
NB = Numbers of Internal Beams
NNP = Number of massless node points
NPIN = Number of pinned beams
NUB = Number of unsymmetrical beams

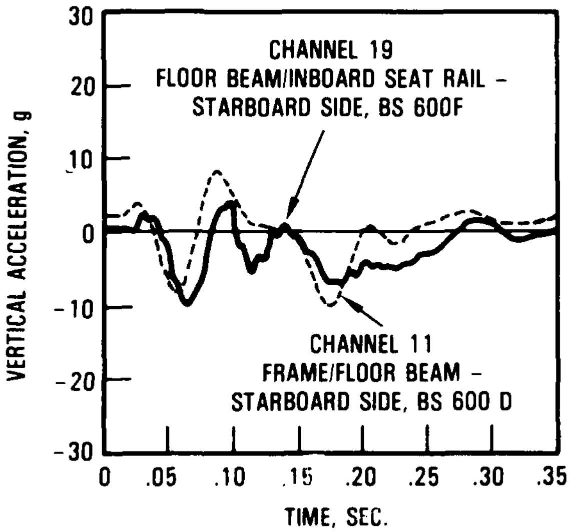
nearly 5 times higher for the hard point condition (32.8 g versus 6.8 g). The fuselage crush in the region of the tanks is approximately 2 inches versus 24 inches for the corresponding soft frame. These results are synonymous with the comparison of references 9 and 10, whose floor accelerations are shown in figure 3-6. As one might expect, the attachment beam loads and floor load interaction curve (LIC) data indicate potential load exceedance for case 3. When mass is added to the end points (case 4) which corresponds to the approximate weight associated with the forward (FS 300) and aft bulkheads (FS 600) of the forward fuselage of the CID configuration, the peak acceleration reduces to 22.3 g, the fuselage crush increase to 5.8 inches. However, the beam forces and LIC values still appear excessive. Case 2, which is similar



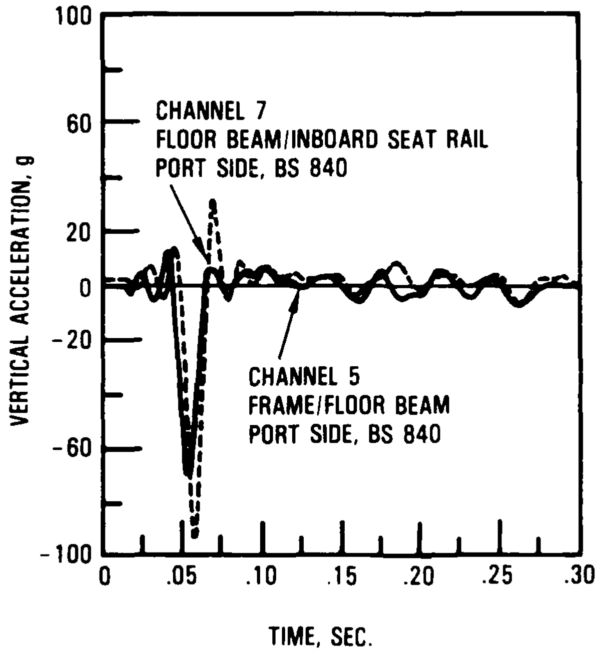
POST TEST VIEW



POST TEST VIEW



(a) RESULTS OF NARROW-BODY AIRPLANE FUSELAGE (SOFT FRAME) SECTION TEST (REFERENCE 9)



(b) RESULTS OF NARROW-BODY AIRPLANE FUSELAGE CENTER SECTION (HARD POINT) TEST (REFERENCE 10)

Figure 3-6. Comparison of Test Results; Hard Point (Reference 10) Versus Soft Frame (Reference 9)

TABLE 3-3. ANALYSIS RESULTS

PARAMETERS	CASE NUMBER											
	1	2	3	4	5	6			7			
						a	b	c	a	b	c	d
● Fuel Tank Peak Acceleration, g_p												
Forward Tank	6.8	8.0	32.8	23.6	20.6	15.9	16.1	12.2	18.9 19.4	21.6 26.4	22.0 28.3	17.0 17.2
Aft Tank	6.5	8.4	30.8	21.1	17.7	15.9	16.1	12.2	12.7 11.5	16.2 14.0	14.8 13.3	11.8 11.3
● Long Duration Pulse g_p (Δt, seconds)	6.8 (.055)	8.0 (.070)	30.0 (.085)	25.5 (.075)	22.0 (.075)	10.2 (.095)	9.8 (.100)	8.0 (.120)	20.0 (.100) 12.2 (.120)	24.0 (.090) 12.7 (.100)	24.0 (.110) 11.4 (.125)	21.6 (.110) 10.6 (.150)
● Relative Tank - Displacement, Inches	.16	.16	.50	1.6	3.8	0	0	0	1.6	1.7	-	-
● Fuselage Crush (Inches)												
Minimum	24.3	20.6	.9	2.8	3.9	18.8	18.8	13.0	8.4	7.5	6.4	6.0
Maximum	24.4	25.0	2.3	5.6	8.3	20.0	20.0	15.0	14.4	14.5	14.0	14.0
Average	23.35	22.8	1.7	4.2	6.1	19.4	19.4	14.0	11.2	11.0	10.2	10.0
● Time for Impact Velocity to Reduce to Zero (sec.)	.150	.145	.055	.090	.115	.16	.16	.20	.16	.16	.16	.16
● Attachment Beam Forces, lb. x 10^4												
Maximum	1.0	1.1	4.1	2.5	4.5	2.1	2.1	1.4	4.0	5.6	6.0	3.6
● Load Interaction Curve (LIC) Value												
Maximum	.75	.75	1.5	1.6	1.7	.53	.46	.62	1.1*	1.08*	1.06*	1.02*

* Relates to overall fuselage shell bending and vertical shear; all other model results refer to floor beams.

to case 1 except the occupant masses are removed, shows about the same results as case 1. The fuel tank peak g increased to 8.4 g. Case 5 represents a center section region (FS 620 - FS 820) in both underside crush characteristics and mass. The results when compared to case 4 show a trend for less severity. The fuel tank peak g reduces slightly (~4.2 percent), the average crush increases (~23 percent), the peak attachment loads reduce (~20.8 percent), and the time for the initial velocity to reduce to zero is increased to 0.115 seconds from 0.090 seconds.

Case 6 represents a 300 inch segment of fuselage. To keep the model within practical size for KRASH limitations and for economical computer runs the frame spacing is 60 inches or 3 bays worth. The results are compared to case 1 since both analyses are based on soft frame section data. Case 6 is divided into three models each with a different variation in tank attachment floor lateral or longitudinal beam stiffness, as is noted in table 3-2. The fuel tank peak acceleration for case 6 varies from 12.2 g to 16.1 g as compared to 6.8 g for case 1. The fuselage crush varies from around 14 inches to 20 inches versus 24 inches for case 6 versus case 1. Beam forces for case 6 are higher than for case 1. The lower beam stiffness representations for case 6C (table 3-2) appear to yield closer results to case 1. Case 6 represents a section weight of 17890 pounds, including occupants and fuel tanks. The case 1 representation is 13660 pounds, the difference being in the number of occupants included. Considering the segment length that each represents (120 inches long versus 300 inches), case 1 is much more densely loaded. Thus, one would expect lower acceleration and more crush than for a more densely loaded section.

Case 7 is the stick model used in the CID validation phase and modified to incorporate the representations of two auxiliary fuel tanks each in the forward and aft fuselage regions. The fuselage external springs represents underside crush which varies from soft structure to hard points at FS300, FS620, FS820, FS960, and FS1400 locations, as noted in figure 3-7.

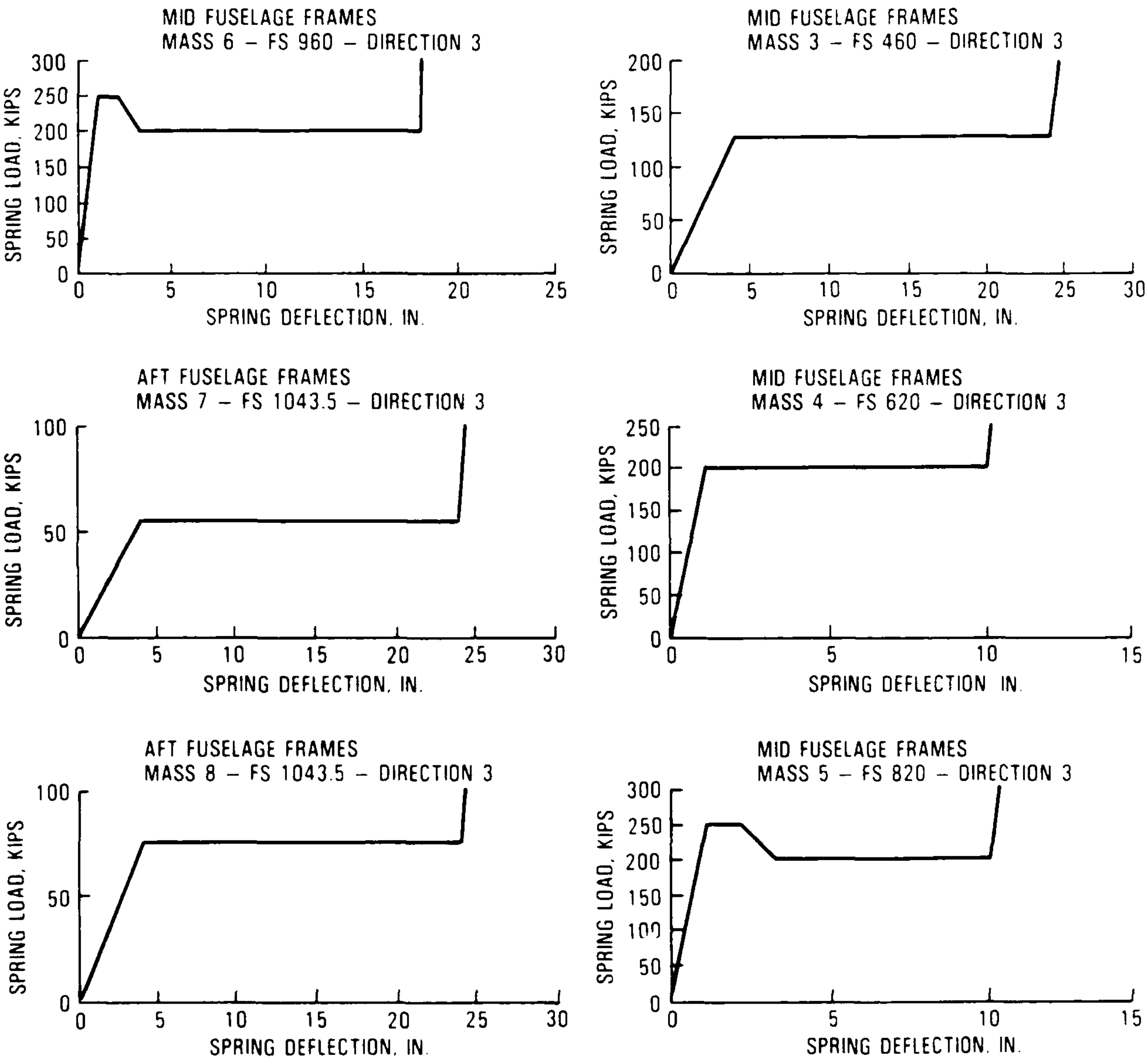


Figure 3-7. Fuselage Load-Deflection Curves for Baseline CID Stick Model

The vertical sink speed for this set of cases was 22 ft./sec. because it represented the limit at which overall fuselage strength (LIC $\leq$ 1.0) would be maintained based on the reference 8 analysis results. Case 7c is the same as 7a except that the condition includes a forward velocity of 260 ft./sec. and a ground coefficient of friction = 0.5. The fuel tanks peak accelerations for this set of cases varies from 11 g to 28 g. The crush ranges from 6 inches to 14.5 inches. The beam forces are excessive for all the case 7 runs, although these results show that the lowest forces occur when the beam attachment stiffness is lowest (case 7d). While the magnitude of the beam forces appears relatively high, these forces are comparable to the force levels reached in case 3 which represents a stiff light structure, and to case 5 which represents a wing center section.

All the results shown in table 3-3 are for a so-called heavier 405 gallon tank. The effect of changing the auxiliary tank mass from 4000 to 3000 pounds was also investigated for one case. Case 6b was rerun with the lower fuel mass. The results (not tabulated) show an increase in the fuel tank mass peak acceleration from approximately 16 g to 20 g and a slight reduction of the beam attachment peak load of approximately 10 percent. All other parameters are about the same.

In addition to the peak acceleration the longer time pulse associated with each impact condition is shown in table 3-3. For cases 1 through 5 the fuel tank mass peak acceleration is the primary pulse. For the case 6 the longer duration pulse is around 0.10 to 0.12 seconds and between 8 g and 10 g peaks, which is 33 to 40 percent lower than the transient peak values. For the case 7 set of runs the longer term pulse peaks are not too different than the transient peaks values; and in some instances are higher.

The analysis results suggest that if a 20 ft./sec. to 25 ft./sec. vertical impact velocity test is performed with a cylindrical auxiliary fuel tank mounted in a cradle supported from the passenger floor installed in a 6-bay "soft" frame section, there would be little likelihood of:

- Floor support failure
- Attachment beam failures
- Higher accelerations than that experienced in previous narrow-body sections impacted at 20 ft./sec.

The crush of the fuselage underside would be less than 24 inches. Considering that the fuel tank installed in the frame section appears like that shown in figure 3-8 and that the failure mode could be much like a section without cargo as shown in figure 3-6a, there is a distinct potential for contact between the distorted fuselage underside structure and fuel tank structure. The analyses show that the section CG moves down 29 inches for such an impact, which increases this potential interaction. A test at the 20 ft./sec. level with the smaller 330-gallon fuel tank will decrease the downward motion of the fuel tanks, but the lower fuselage structure would still deflect in a fashion somewhere between that shown without cargo (figure 3-6a) or with cargo (figure 3-9).

Typically, several auxiliary fuel tanks as a system would be installed in an airplane. Figure 3-10 shows nine 330 gallon-tanks in a narrow-body executive configured airplane. Four of the tanks are in the forward cargo compartment and five are in the cargo compartment aft of the main landing gear bulkhead. As one can see from figure 3-10 there is substantial clearance between the lower extremity of the fuel tanks and the lower fuselage in the forward fuselage compartment. From figure 2-2 the anticipated crush in this region is approximately 12 inches. Thus, the use of fuselage fuel tanks of the cylindrical configuration in this region may not be critical from a crush condition. However, for the mid-to-aft cargo compartment this situation can be more critical, particularly the further aft the tanks are installed. From figure 2-2 it can be observed that more crush could be experienced around FS 1200 and at the same time the shape of the fuselage in this region (figure 3-10) reflects less clearance to begin with. However, for a more representative passenger transport airplane configuration it is unlikely that more than a total of four 330-gallon auxiliary tanks (2 forward and 2 aft)

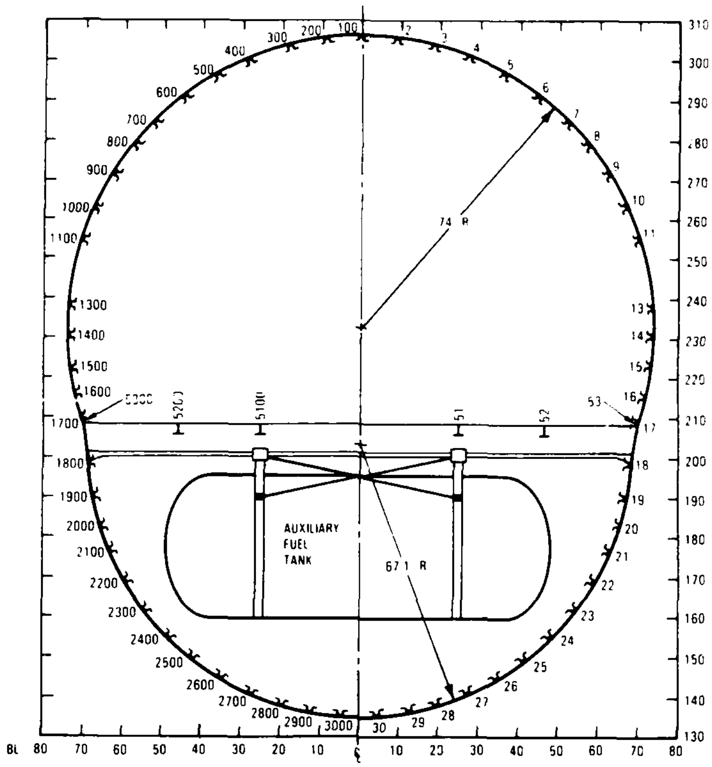


Figure 3-8. Installation Layout

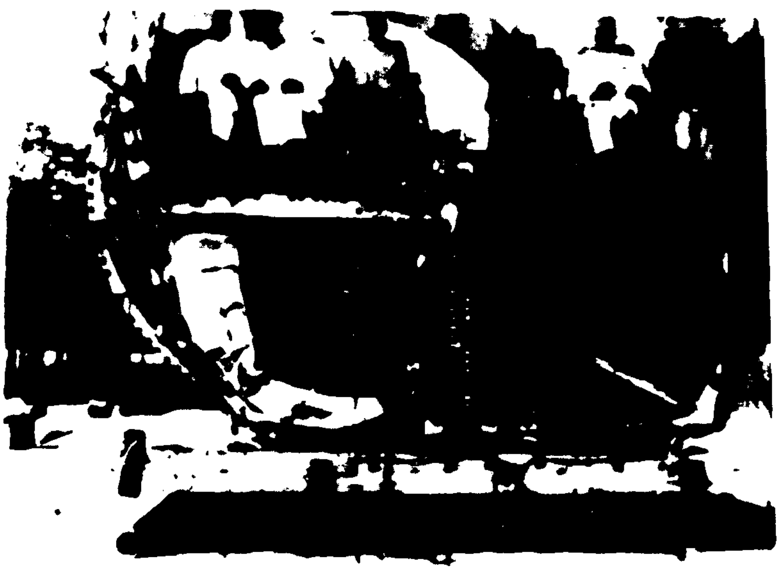


Figure 3-9. Fuselage Underside Crush With Cargo (Reference 1)

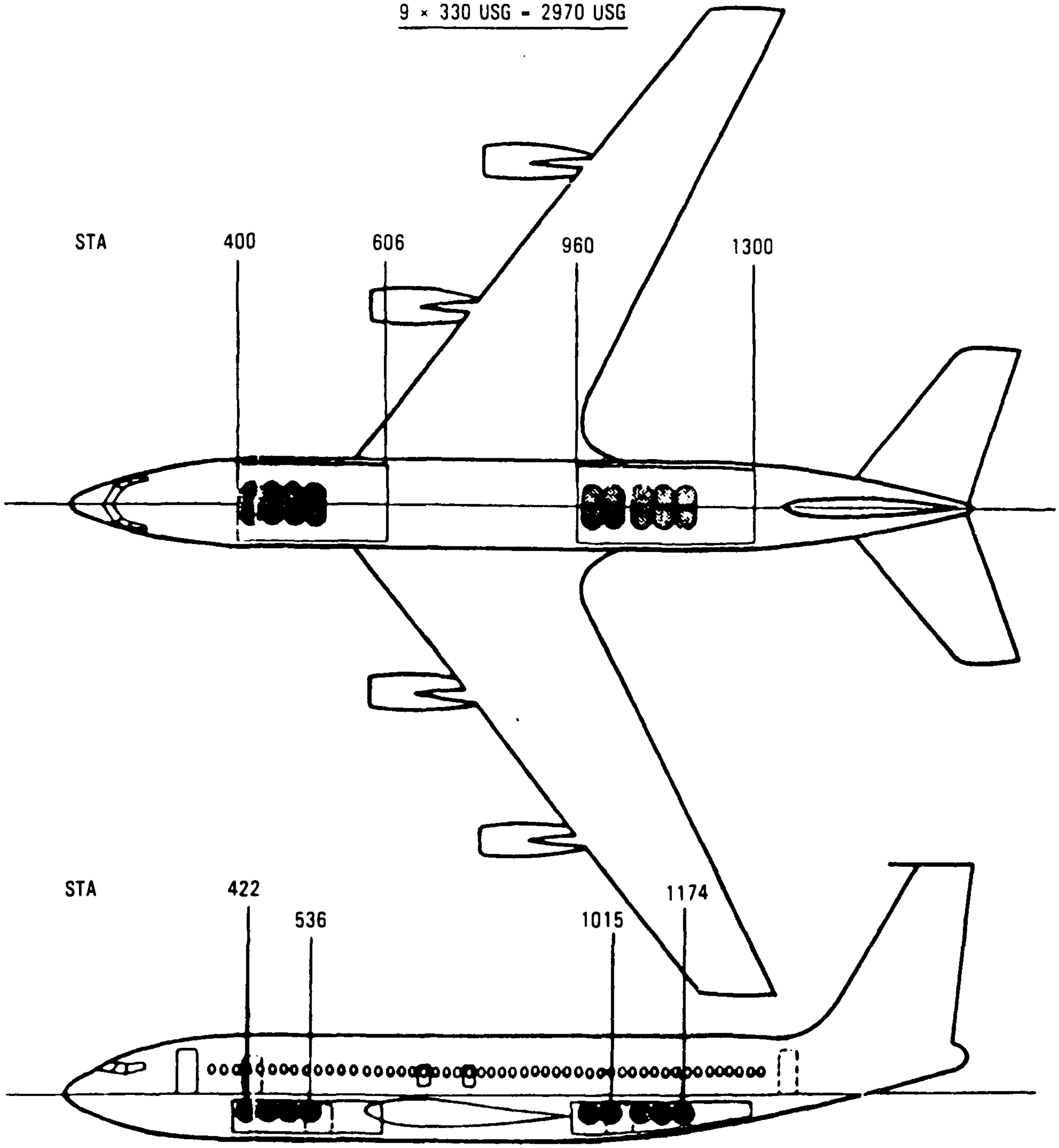


Figure 3-10. Layout of Nine 330-Gallon Auxiliary Fuel Tanks in a Narrow-Body Airplane

would be installed and the installation would be closer to the hard bulkhead structure.

A test of the cylindrical auxiliary tank in which hard structure such as major bulkheads (nose gear, main gear, and aft pressure) or reinforced strength sections (wing center section) are available is represented by cases 3, 4, and 5. Without appropriate mass (case 3) the peak acceleration response will be quite high (32.8 g). The potential for beam attachment failures and passenger floor beam failure increases dramatically, as noted by LIC values >4. The fuselage underside could be limited to less than 2.3 inches. A test involving "hard points," to be realistic, should include mass that is normally associated with the section. This latter condition would reduce the peak accelerations to a range of 20.6 g to 23.6 g and increase the crush to a range of 5.6 to 8.3 inches. The movement of the tank as a result of the impact is about 10 inches down relative to the ground contact point, which means that interference with the crushed lower fuselage is lessened. The section failure most likely will not form the cusp shown in figure 3-9 and thus tank penetration may not occur. However, the beam attachment and floor beam loads appear sufficiently high to cause failure. Also, to reduce the accelerations and increase the crush, as noted, the 120-inch, 6-bay test specimen weight must be between 36650 and 46250 pounds.

A test of cylindrical tank in a 300-inch section should produce similar results as a test with a 120-inch section provided the loading density and structural properties are comparable. Obviously, the longer section imposes both heavier weight and length requirements on the test facility. Theoretically, a B707 specimen of this size is a full forward fuselage which could range from the nose gear bulkhead to the wing center section leading edge.

Cases 7a through 7d represent potential results for a full-scale test. Unfortunately, the stick model does not detail the floor structure to which the beams attach. The relative stiffness of the fuel tank attachments and fuselage shell section represented in the model most likely is not realistic

of the fuel tank to floor attachment stiffeners. Thus, the high fuel tank beam attachment analytical results are not considered reliable. The larger expanded model used in support of CID test might be more useful, but at a computer run time and cost in excess of the costliest model described in table 3-2. Since a full-scale test of another narrow-body transport airplane is unlikely, the expanded model could be run after section modeling and testing is completed and the results are compared.

3.1.1.2 Longitudinal Direction Impact

Several KRASH runs were made to evaluate the mass responses resulting from a longitudinal pulse or frontal impact. The front impact representation was the same as that described in reference 1 except for the addition of two auxiliary fuel tanks in both the forward and aft fuselages. This model is shown in figure 3-11. The model to investigate a longitudinal pulse is the same 120-inch 6-bay model used in the vertical impact study described in Subsection 3.1.1.1 (figure 3-6) except that instead of crush springs located at the fuselage underside, the floor masses are provided with a 14.2 g, 36 ft./sec. triangular pulse excitation in the longitudinal direction. Table 3-4 summarizes the different cases and results of the longitudinal impact analyses. In all, 9 longitudinal pulse cases were run. Cases 1 through 6 represent an airplane impact into a 90-degree wall in an effort to produce a primary longitudinal response. Case 1 and 2 were performed for a 50 ft./sec. impact velocity differing only in the stiffness of the auxiliary fuel tank mounts. Cases 3-6 represent 40 ft./sec. impacts with different fuselage mount stiffnesses. The mount stiffness for cases 1 and 4 are equal as are the stiffnesses for cases 2 and 5. Cases 7 and 8 provide the longitudinal responses full airplane stick model analysis in which the impact and ground parameters are; forward velocity = 262 ft./sec., sink speed = 22 ft./sec., pitch attitude = 0 degrees and ground coefficient of friction (μ) = 0.5. The vertical responses for this case were provided previously in table 3-3. Case 9 represents a 6-bay 120-inch section subjected to a triangular pulse defined as 14.2 g peak 36.2 ft./sec., rise time (t_r) = 0.07 seconds. This model assumes all floor masses are simultaneously subjected to this pulse. This pulse was selected so as to compare with a previous FAA test (reference 4) in

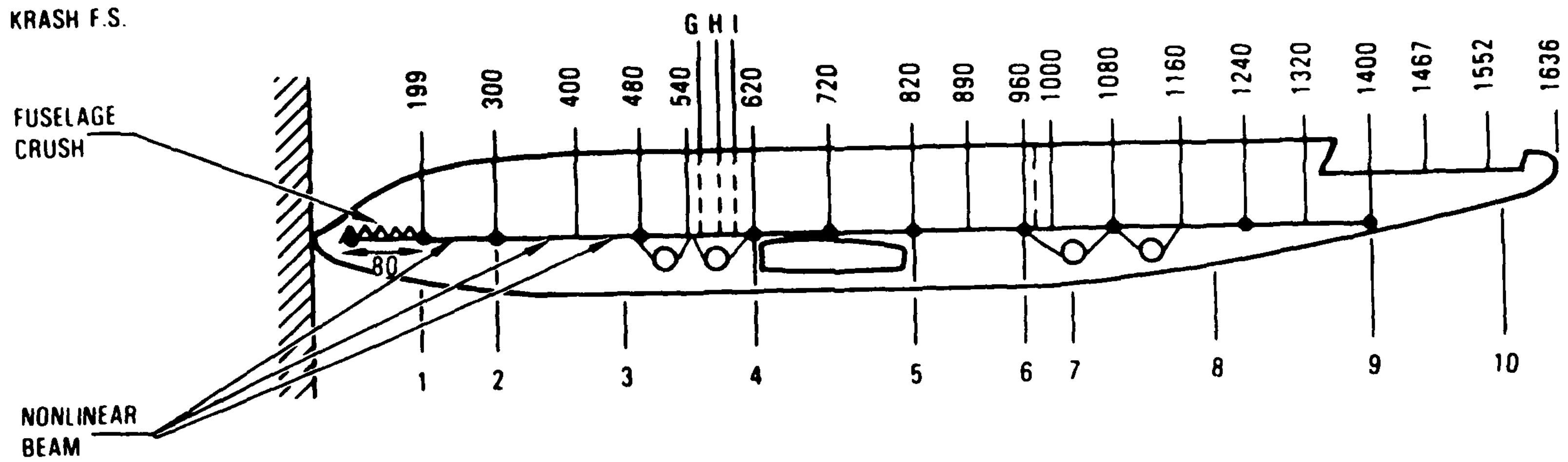


Figure 3-11. Longitudinal Impact Analyses Model

TABLE 3-4. SUMMARY OF RESULTS LONGITUDINAL IMPACT ANALYSES (Sheet 1 OF 2)

PARAMETER	50 FT./SEC., FRONTAL IMPACT FULL AIRPLANE		40 FT./SEC., FRONTAL IMPACT FULL AIRPLANE				COMBINED IMPACT FULL AIRPLANE		36 FT/SEC LONGITUDINAL PULSE SECTION
	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8	CASE 9
FUEL TANK PEAK ACCELERATION, g									
Fwd. Fus. #1	15.5	10.5	17.5	10.6	10.0	2.7	6.8	5.7	15.9
Fwd. Fus. #2	12.3	10.6	14.9	9.9	9.8	2.7	6.4	4.9	15.9
Aft Fus. #3	11.1	10.8	13.8	8.1	9.4	2.8	7.6	5.0	NA
Aft Fus. #4	10.8	11.2	16.0	8.7	10.1	2.8	8.6	5.3	NA
MAXIMUM RELATIVE VERTICAL DISPLACEMENT, IN.	1.7	1.6	1.2	1.2	1.2	.1	0.9	0.8	0
PEAK ATTACHMENT BEAM FORCE, LBX10[4]									
Fuel Tank 1	3.6	3.4	6.4	2.7	2.9	1.1	5.2	3.7	1.5
Fuel Tank 2	3.2	3.5	5.0	2.7	2.9	1.1	6.0	3.5	1.5
Fuel Tank 3	3.7	3.7	4.8	2.9	3.0	1.1	3.5	3.1	NA
Fuel Tank 4	3.7	3.8	5.7	3.1	3.2	1.1	4.4	3.2	NA
FLOOR (SECTION) PEAK ACCELERATIONS, g									
FWD - (MASS 3)	63.4	67.8	86.0	57.8	70.8	53.9	5.6	5.8	14.7
(MASS 4)	49.0	47.0	49.0	37.0	45.0	60.0	7.4	5.4	14.7
	18.8	26.7	14.2	16.6	21.5	31.2	7.1	6.0	14.7
Center - (MASS 5)	17.6	16.	17.5	16.8	14.2	11.4	6.9	6.4	14.7
(MASS 6)	17.7	18.9	12.4	13.1	13.5	14.5	6.9	6.2	14.7
AFT - (MASS 7)	17.2	17.1	14.7	12.8	13.3	13.2	7.3	6.9	14.7
(MASS 27)	11.4	13.5	15.2	12.4	10.1	10.7	8.7	7.6	14.7

NA = Not Applicable

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TABLE 3-4. SUMMARY OF RESULTS LONGITUDINAL IMPACT ANALYSES (Sheet 2 of 2)

PARAMETER	50 FT./SEC., FRONTAL IMPACT FULL AIRPLANE		40 FT./SEC., FRONTAL IMPACT FULL AIRPLANE				COMBINED IMPACT FULL AIRPLANE		36 FT/SEC LONGITUDINAL PULSE SECTION
	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8	CASE 9
FLOOR (SECTION) EQUIVALENT TRIANGULAR PULSE									
Peak g	10.4	10.4	9.5	9.5	9.5	9.5	5.3-7.0	5.3-7	14.7
and Δt (Sec)	.200	.200	.200	.200	.200	.200	.160-.115	.160-.115	.190
STIFFNESS LB/IN X 10^4 AND FREQUENCY, (HZ)									
Attach. Beams									
Vertical	8.5(19)	3.3(16)	85.(60)	8.5(19)	3.3(16)	.08(1.9)	8.5(19)	.85(16)	5.4(100)
Longitudinal	7.3(18)	7.3(18)	73(183)	7.3(57)	7.3(18)	.70(5.7)	73(179)	7.3(18)	15.4(200)
Support Structure									
Vertical	900(180)	900(180)	900(180)	900(180)	900(180)	900(180)	900(180)	900(180)	5.5(170)
Longitudinal	450(120)	450(120)	450(120)	450(120)	450(120)	450(120)	450(120)	450(120)	8.5(570)

which a similar airframe section loaded only with occupants was performed and data is available for review.

The 50 ft./sec. frontal impacts show a decrease in fuel tank peak acceleration as the tank to floor attachment stiffness is reduced. This trend holds also for the 40 ft./sec. frontal impacts. The stick model floor responses actually section responses, show high peak g's in the forwardmost region and a reduction in peak levels the further location from the impact. The peak g's are short duration transients and the tabulated data is based on 5 msec. plot intervals. Thus, it is conceivable that some actual peaks are not listed which might make the trend appear inconsistent. Based on mass impulse over a 200 sec. duration the fuselage response can be characterized as a triangular pulse of approximately 10.4 g and 9.5 g for the 50 ft./sec. and 40 ft./sec., respectively. The 40 ft./sec. frontal impact shows four stiffness variations. The stiff attachment indicates that the fuel tank response is in sync with the fuselage and floor. By the same token an attachment stiffness reduction by a factor of 100 will literally isolate the fuel tank response. However, as noted in the discussion of the vertical responses in Subsection 3.1.1.1 the stick model representation of the floor beams is most likely too stiff. The attachment beam forces in all but the softest mount imply relatively high and probably excessive loads.

The stick model results, cases 7 and 8, suggest that the longitudinal peak pulse is reduced to approximately 5 g to 8 g, depending on beam attachment stiffness. The beam attachment loads are relatively high for these cases. However, these cases also produce significant vertical loads since it is a combined vertical-longitudinal impact in which the primary pulse is vertical.

The longitudinal pulse condition, case 9, indicates that the fuel tanks might respond at a peak g slightly higher than the 14.2 g pulse, but that the attachment loads are lower than for all the other cases with comparable beam attachment stiffness. This case assumes that the floor pulse is prescribed. The closest comparisons with this condition is case 3. In this case floor

pulses show peak accelerations between 12.4 g and 17.5 g and fuel tank peak accelerations between 13.8 g and 17.5 g. However, the long duration pulses associated with case 3 is 9.5 g peak for 0.200 seconds.

The relative vertical displacement between fuel tanks does not exceed 1.7 inches for any of the representations. This indicates that allowance of flexing of 2 inches between tanks most likely will suffice for a severe longitudinal pulse. The analyses for the vertical impact showed one case involving hard point structure in which this displacement value was exceeded (table 3-3, case 4, 3.8 inches).

The longitudinal pulse analyses results indicate that auxiliary fuel tank response can vary substantially depending on analytical representation. For example, cases 7 and 8, which might be the more realistic scenarios, suggest that fuel tank responses are between 5 g and 8 g dynamically, but with substantially high attachment loads unless the mount stiffness isolates the tank or plastic deformation occurs, which was not included in the modeling.

By contrast, frontal impacts produce significant longitudinal transient pulses with peak values of 8 g to 17 g, depending on impact velocity and fuel tank attachment properties. However, a longer duration pulse of ~.200 second would produce about 9.5 g peak triangular shaped response throughout the fuselage for a 40 ft./sec. impact. This magnitude of pulse does not compare favorably with the 14.2 g peak, 0.150 second, 36 ft./sec. induced floor pulse to an airframe section when one considers fuel tank acceleration responses and attachment beam loads.

3.2 CONFORMABLE TANKS WITH BLADDER

Conformable tanks with bladders supported in a dedicated structural box is the type of configuration which is in use in many current narrow-body and wide-body transport airplanes. The structural boxes are generally made of externally stiffened panels and are designed to support the bladder cell for all operational conditions, including the crash environment. This type of tank is generally located in the lower fuselage cargo compartment. The

designs reviewed employ integral fitting attachments in the box to transfer all the loads to the aircraft floor and airframe shell at specific locations through predetermined load paths.

A general arrangement of an installation in a narrow-body airplane is shown in figure 3-12. The body tank is supported from the passenger floor beams. The tank is composed of an aluminum honeycomb outer shell with two bladder cells inside. The tank is supported in such a manner as to preclude body structure deflections to load the fuel tank and clearances are provided around the tank to adjacent structure.

The fuel tank (figure 3-13) consists of two modules which are constructed of hot bonded aluminum honeycomb panels fastened together with angles. This is a typical corner of the tank. Honeycomb thickness varies from 1/2 inch to 1 3/4 inch with face sheets of 0.04 to 0.07. The face sheets have corrosion inhibiting adhesive primer applied prior to bonding and they receive an additional coat of paint after bonding. Dense core is provided for stability in fastener attachment areas. Edges of the panels are potted. Panels are fastened together with angles by bolts and lockbolts. A typical insert consists of a metal plate which is bonded to the tank panels. These are used for fuel, vent, and drain line penetration and for access door attachment. A typical module joint consists of angles bolting the tank walls to the intermediate bulkhead. An external splice plate is installed in selected locations. The tank is pressure-sealed on the inside by fillet sealing fasteners, angle fittings, etc. Corrosion protection sealing is added to selected areas on the outside of the tank. Forward and aft loads are reacted into the skin through fittings and two struts, one strut on each side of the tank (figure 3-14). The struts attach at pin joints on both the tank and the body structure. Spherical bearings are installed at both joints to provide for relative movement between the tank and structure due to fuselage deflections from pressure and tank loads. Tank loads are transferred into the frames and skin by added support structure between body frames. The tank attachment layout is shown in figure 3-15.

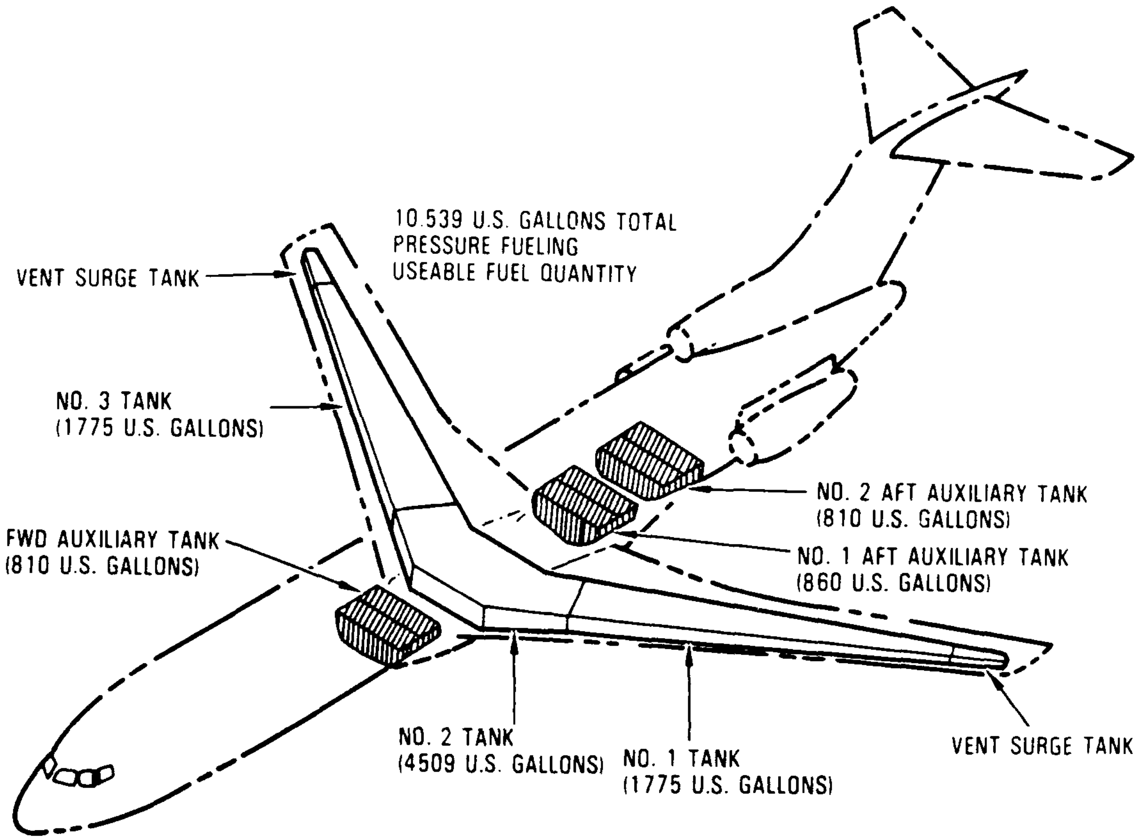


Figure 3-12. Fuel Tank Arrangement in a Narrow Body Airplane

The fuel and vent lines that connect the auxiliary tanks to the main fuel system incorporate drainable and vented shrouds. Additionally, these lines are either designed to break away from the auxiliary tank or sufficient stretch is provided to accommodate tank movement without causing fuel spillage. Hoses that are required to stretch are subjected to what is referred to as the guillotine test. The hose is pressurized and clamped at both ends to simulate its mounting in the aircraft, then a sharp-pointed load is applied in the middle of the hose. The hose must not leak when stretched to its maximum.

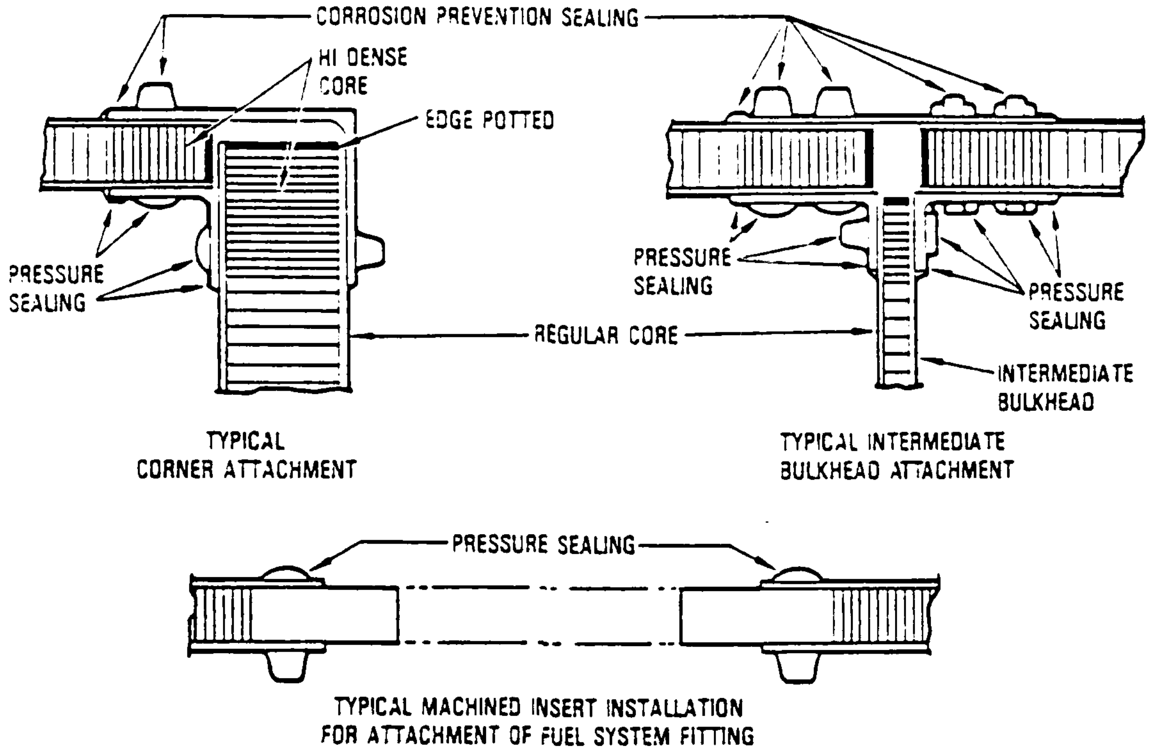


Figure 3-13. Fuel Tank Shell Construction

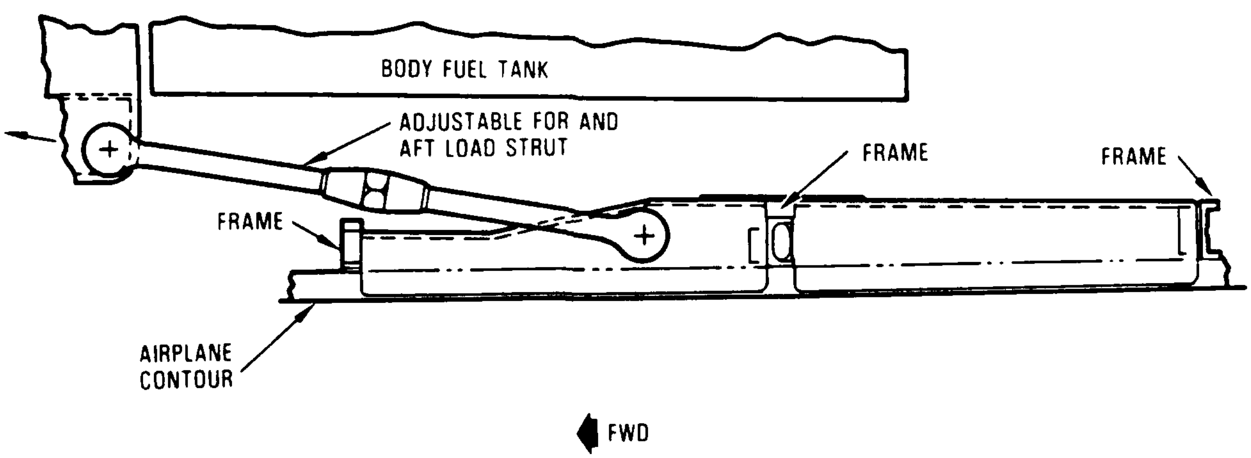


Figure 3-14. Fore and Aft Load Fittings

Alternate designs can have the fuel tank mounted to the cargo floor only or supported solely from the passenger floor. The location and general arrangement of the fuselage fuel tanks in a current wide-body (cargo version) airplane is shown in figure 3-16. The load paths for the wide-body aircraft is shown in figure 3-17. In this design, gaps are maintained outboard of the upper tank box fittings to assure that the tank box does not experience loads from the fuselage.

3.2.1 Analysis Results

The results of the analysis for the double-wall cylindrical tanks, presented in Subsection 3.1.1, can be interpreted for the conformable tanks which contain a bladder supported in a dedicated structural box in the following manner:

- Passenger Floor Supported Tanks

  All the results shown in tables 3-3 and 3-4 are applicable, as well as the Subsection 3.1.1 discussion. Fuel tank capacity would alter the acceleration responses and attachment loads somewhat, but the crush of the fuselage should not be appreciably affected. The double-wall cylindrical tanks can come in different sizes (capacities) thus, the Subsection 3.1.1 results would be similarly affected.

- Cargo Floor Mounted Tanks

  This case was not run, but the most obvious affect would be that the lower fuselage crush could be critical for this type of support. For one thing, the crush of the fuselage frames under a 22 ft./sec. vertical velocity impact can produce crush distances of 10 to 20 inches depending on the proximity of the fuel tank location relative to a hard point. With the fuel tank located directly on the cargo floor the fuselage underside crush distance would be affected. Tests with and without cargo of a narrow-body airplane section (figures 3-10 and 3-11) show that the cusp formation at the fuselage bottom centerline is altered. Tests with and without cargo of a wide-body section are shown in figure 3-18. The addition of the cargo mass causes complete collapse of the fuselage below the cargo floor, a condition that did not occur without the cargo.

- Combined Passenger and Cargo Floor Attachments

  This particular installation configuration is vulnerable to cargo floor collapse and penetration resulting from substantial lower

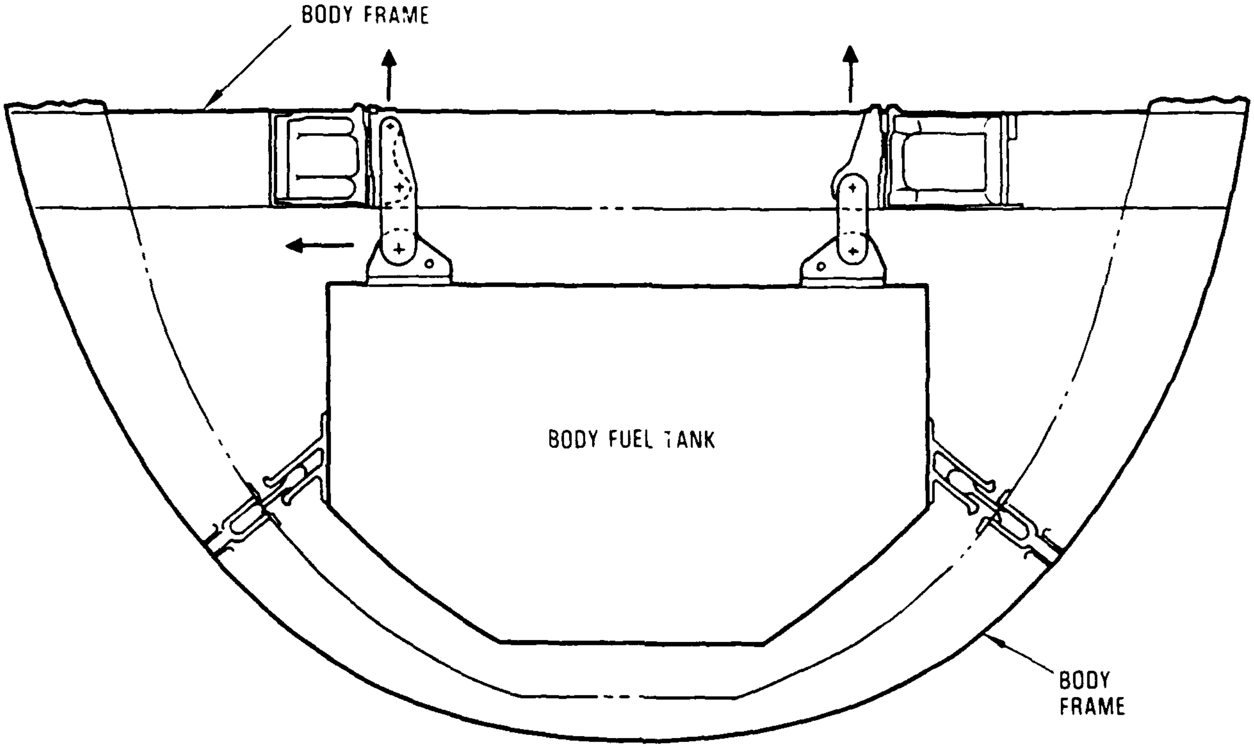


Figure 3-15. Tank Attachment Layout

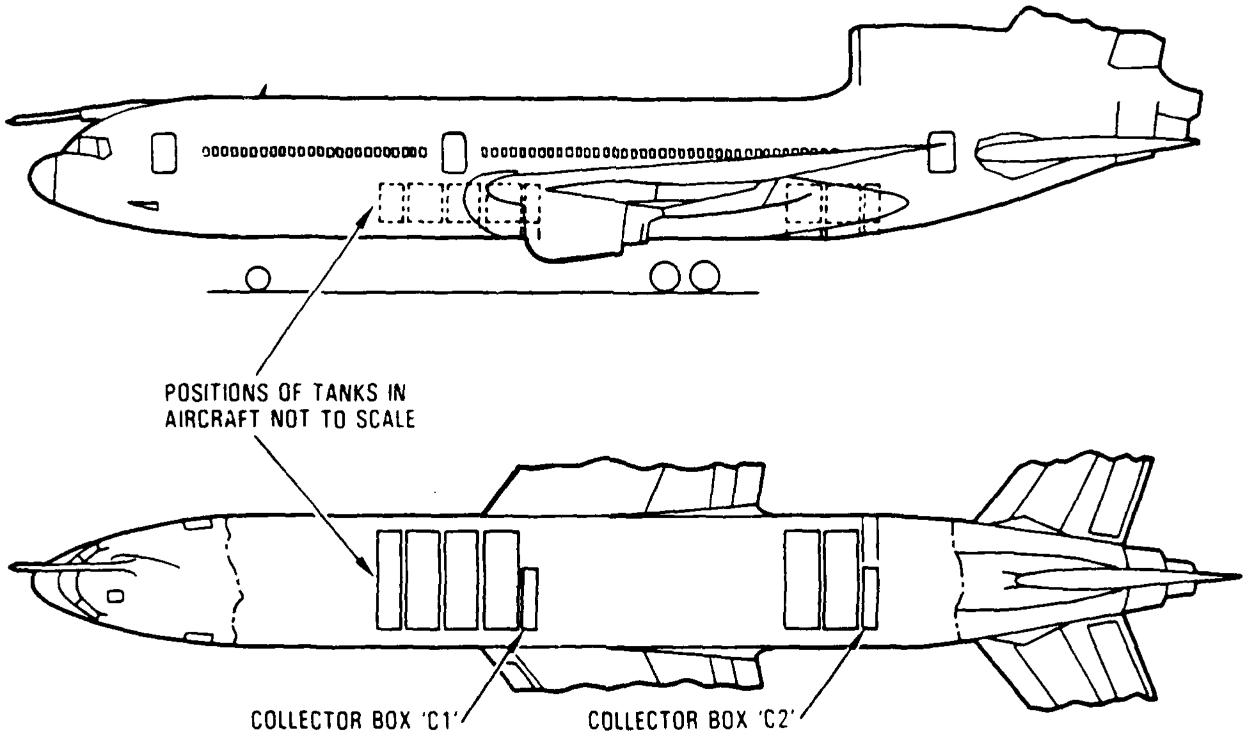


Figure 3-16. Location and General Arrangement of Auxiliary Fuel Tanks in Wide-Body Airplane

fuselage crush as well as possible higher attachment loads. KRASH runs were made to obtain fuel tank mass acceleration, fuselage crush and attachment loads. The model was the same as described in Subsection 3.1.1, case 6, except that the weight of each of the two tanks was higher and the associated mass moments of inertia were likewise increased. The variation in beam attachment stiffness was also investigated. These cases are referred to as "soft" and "stiff" systems. The properties of this model are described in table 3-5.

The results of the analysis with the conformable tank installation is shown in table 3-6, along with a similar double-wall cylindrical tank analysis. The differences in the analysis results between the conformable and the double-wall cylindrical installation reflect differences in:

- Fuel tank masses
- Installation techniques
- Model floor and crush spring representations

The conformable tank weight used in the analysis is 6,600 versus 4,000 pounds for the double-wall cylindrical tank. As noted in Subsection 3.1.1.1 the lower fuel tank mass results in higher peak accelerations for the same impact condition. Doubling the fuel tank mass for the cylindrical tank analysis could reduce the peak values to an 8 to 10 g range.

The conformable tank installation includes a drag link to take out longitudinal loads. While the analysis is strictly a vertical impact the drag link is positioned diagonally in the model such that it takes loads in both the ground vertical and longitudinal axis. The double-wall cylindrical tank is modeled with vertical beams attached to the passenger floor (in the same manner as the conformable tank), but with diagonal shear (tension-only) members to transfer longitudinal loads. The frame section model used in the double-wall cylindrical tank is modeled with uniform soft fuselage underside crush springs. The frame section model used with the conformable tanks has end points with stiff springs representing the bulk-heads (e.g., nose-gear and wing center section) with the intermediate soft crush springs, as frames should be.

ASSUMPTIONS MADE:

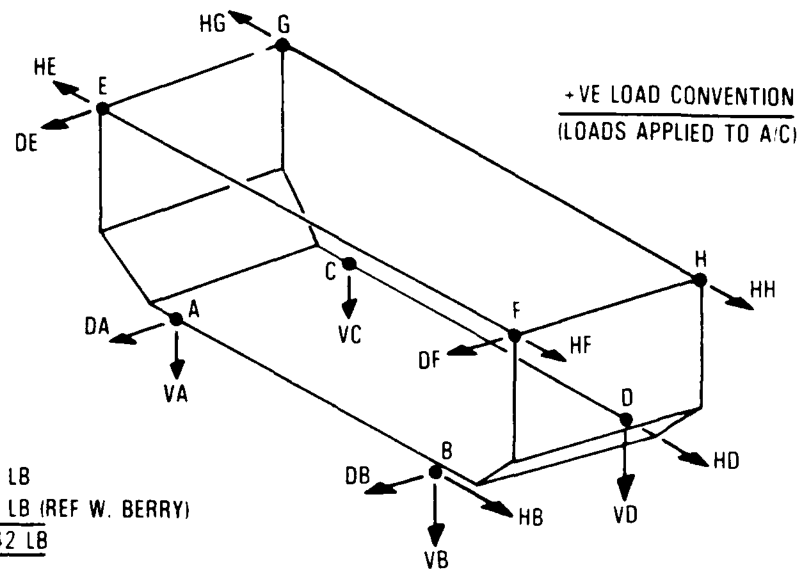
FLIGHT LOADS ONLY –

POINT A: VERTICAL AND DRAG LOAD ONLY
POINT B: VERTICAL, DRAG AND SIDE ONLY
POINT C: VERTICAL LOAD ONLY
POINT D: VERTICAL AND SIDE LOAD ONLY

CRASH CONDITION:

POINT E AND F: FWD LOAD ONLY BY VIRTUE OF SLOPPY LINK
POINTS E, F, G, H: SIDE LOAD USING BUFFER PADS ON CORNERS ONTO FLOOR BEAM PROPS
POINTS A – D: AS FLIGHT CONDITIONS
L.G. ASSUMED AT MID-POINT FORE AND AFT AND SIDEWAYS
C.G. ASSUMED AT CENTROID OF ABOVE AREA VERTICALLY

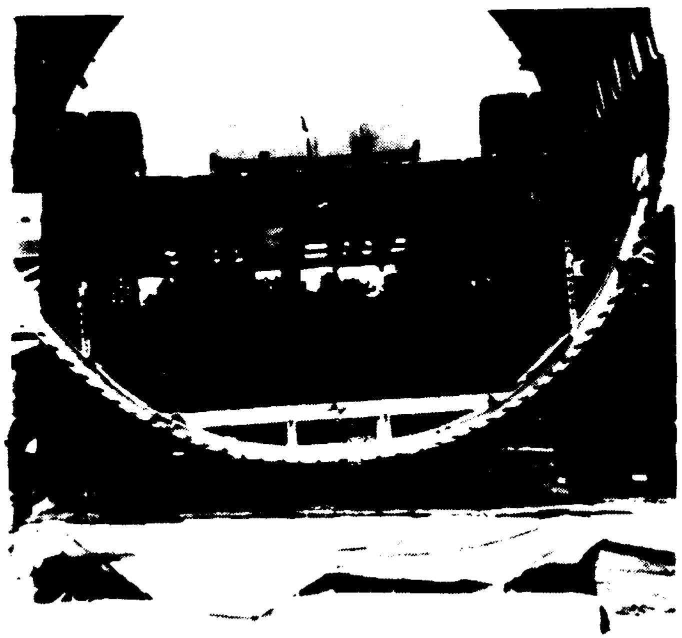
VERTICALLY $\overline{y}$ ABOVE WL 127.5 = 30.723 IN.



FUEL WEIGHT = 9029 LB
STRUCTURE = 1113 LB (REF W. BERRY)
= 10,142 LB

Figure 3-17. Wide-Body Aircraft Fuselage Fuel Tank Load Paths

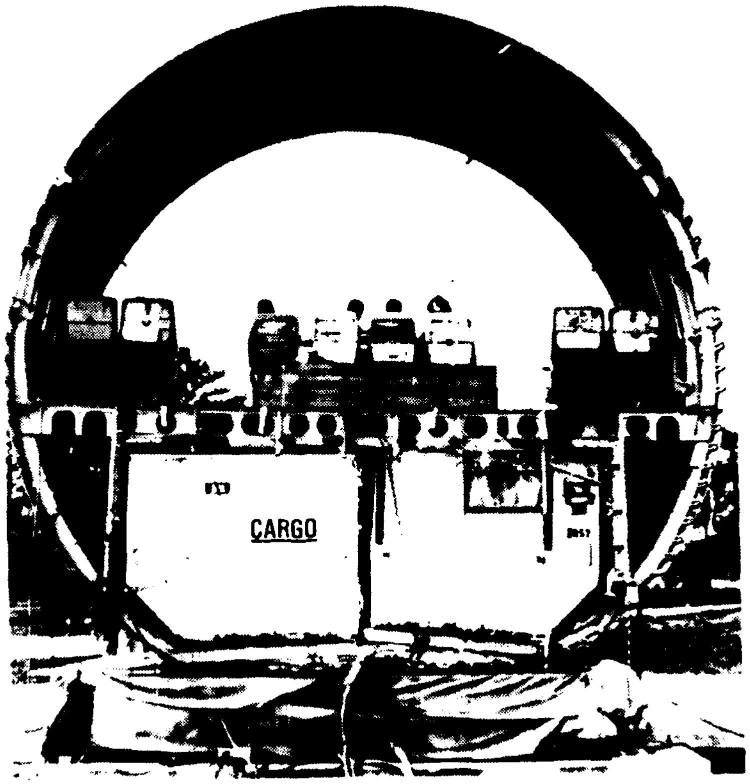
ANTHROPOMORPHIC
DUMMIES REMOVED



NO CARGO

(a) LIGHTLY-LOADED SECTION:
20 FT/SEC IMPACT VELOCITY

ANTHROPOMORPHIC
DUMMIES IN PLACE



(b) HEAVILY LOADED SECTION:
25 FT/SEC IMPACT VELOCITY

Figure 3-18. Wide-Body Frame Section Post-Test Results

TABLE 3-5. MODEL PARAMETERS - NARROW BODY CONFORMABLE TANK ANALYSES

Fuel Tank Weight lb.	=	6,600
Mass Moment of Inertias lb.-in-sec^2		
Ix	=	11,000
Iy	=	6,140
Iz	=	11,000
Beam Attachment Vertical Stiffness lb./in. and (Frequency, Hz)		
Soft System	=	5.9×10^4 (106)
Stiff System	=	5.9×10^5 (337)
Drag Link Stiffness, lb/in. (Frequency, Hz)		
Soft System	=	1.6×10^4 (67)
Stiff System	=	1.6×10^5 (211)
Floor Stiffness, lb/in. (Frequency Hz)		
Longitudinal Direction	=	8.5×10^5 (570)
Vertical Direction	=	5.5×10^4 (146)
Total Section Weight		22,100

TABLE 3-6. COMPARISON OF RESPONSES CONFORMABLE VERSUS DOUBLE WALL CYLINDRICAL FUEL TANKS

Parameter	Conformable Tank		Double-Wall Cylindrical Tank	
	Soft System 1	Stiff System 1	Soft or Stiff System 2	Soft or Stiff System 1
• Fuel Weight, lb	6,600	6,600	4,000	6,600
• Fuel Tank Peak Acceleration, g peak				
Tank No. 1	8.7	10.3	16.0	8.1
Tank No. 2	8.7	10.7	16.0	8.1
• Long Term Triangular Pulse,				
g peak	7.0	7.0	9.8	6.8
Δt, seconds	0.100	0.100	0.100	0.110
• Fuselage Underside Crush, Inches				
Maximum	16.6	16.1	20.0	18.0
Minimum	11.7	11.2	18.8	13.0
Average	14.2	13.8	19.4	15.5
• Attachment Beam Maximum Load, lb X 10^4				
Tank No. 1	2.0	2.9	2.1	2.2
Tank No. 2	1.8	2.9	2.1	2.2

1 Hard end points with soft intermediate frames

2 Only soft frames throughout

The previous analysis of the double-wall cylinder tank in the 300-inch section was revised to modify the crush springs and weight of the tanks to be in agreement with the conformable tank analysis. The results shown in table 3-6 indicate that when like systems are compared the accelerations and crush do show closer agreement.

The comparison in table 3-6 serves the purpose of not only comparing two concepts, but also indicating differences that might exist between installations in frame section versus hard point sections. The affect of the installation with regard to drag or vertical loads transmitted to the lower frame structure has not been evaluated. This is an area for further review as are other installation configurations.

3.3 BLADDER FUEL CELLS FITTED IN THE LOWER FUSELAGE

A current example of this type of tank configuration is in a commercial wide-body transport airplane in which the bladder fuel cells are located below the wing and between the front and rear spars of the wing carry-trough structure. Maximum utilization of available volume is achieved by conforming a bladder cell to the fuselage contour. Figure 3-19 shows a fuel cell layout. In the military version of this airplane, a three-cell tank is located in the forward lower cargo compartment and a four-cell tank is located in the aft lower cargo compartment. Access for maintenance and inspection is provided through the bottom of the fuselage to each cell. The fuel lines are located away from the bottom of the tanks and provide protection against hazards such as collapsing fuselage-mounted landing gear, wheels-up landings, and off-runway incidents.

Case 5, described in Subsection 3.1.1.1 table 3-2, represents a wing center section region of a narrow-body airplane. The section weighs 46,250 pounds with two 4,000 pound auxiliary tanks. By eliminating the two auxiliary tanks, but adding the mass of the tanks to the structure the configuration would be closer to a center section fuel tank representation. Subjecting a revised model (47050 pounds) to a 25 ft./sec. vertical impact results in the following:

- Average crush distance ~ 8.4 inches
- Floor peak acceleration ~ 10.3 g to 14.8 g (12.5 g average)

Prior to the CID test a full-size narrow-body airplane was dropped with a resultant vertical-only impact velocity of 17.0 ft./sec. This particular impact is referred to as the 'Laurinburg' test. The 'Laurinburg' analytical modeling results show approximately 6.7 to 9.9 inches (8.3 inches average) crush in the center section. This compares favorably with post-test measurements. The analysis results also show a peak floor acceleration of 6.0 g to 9.2 g (7.6 g average) in the wing center section region. There were no test measurements obtained to compare to the analysis results. The analytical model included wing structure and fuel mass which accounts for both more crush and lower accelerations at a 17 ft./sec. impact when compared to the 25 ft./sec. analysis results presented in the previous paragraph. Analysis results from the post-CID parametric analysis (reference 2) for 20 ft./sec. to 25 ft/sec impacts show peak accelerations of 10 g to 12 g with a rise time of 0.070 second for center wing section masses. The same analyses show crush in this region of approximately 10 inches. The crash design criteria presented in section 2 suggests a wing center section response of 10.4 g, 0.075 second rise time, 25 ft./sec. velocity change and a maximum crush of 10 inches as the envelope extreme.

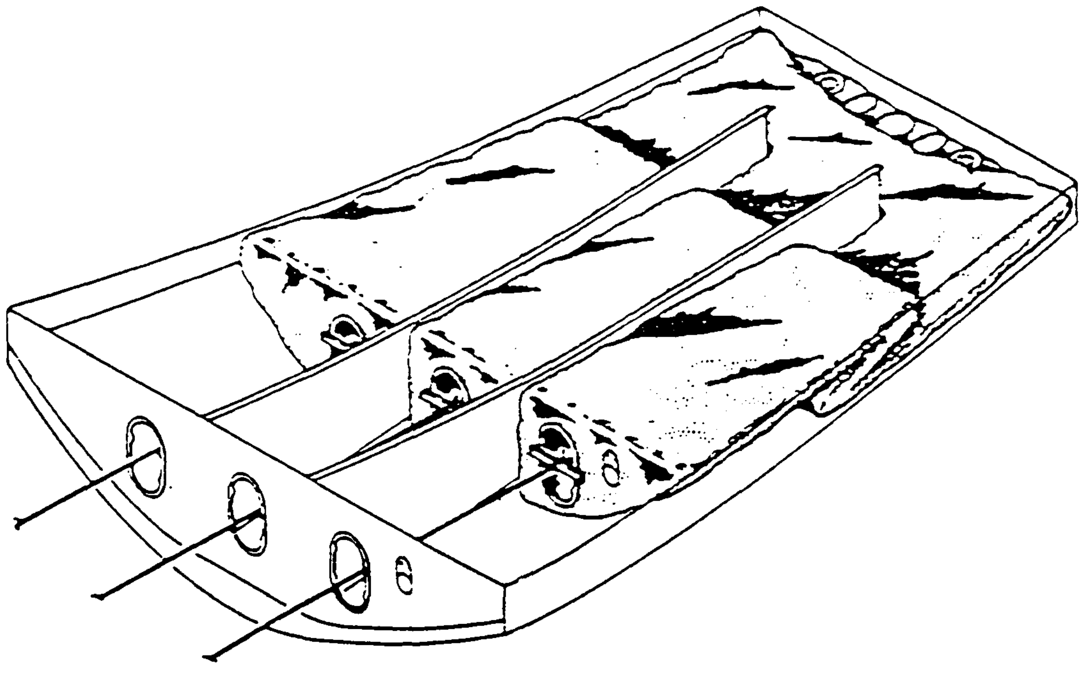


Figure 3-19. Bladder Cell Installation Wide-Body Transport Airplane

SECTION 4

SUMMARY OF RESULTS

The results of the reference 1 study indicate that a test program involving fuselage mounted fuel tanks should be initiated. Contemporary fuselage fuel tank installation configurations include:

- Conformable tank containing a bladder and supported within a dedicated structure.
- Double-wall cylindrical strap in auxiliary tank.
- Bladder cells fitted in the lower fuselage.

Section 2 of this report reviews existing crash design criteria as well as current proposals that could effect fuselage fuel tank installations. Included in the review are the following:

- FAR 25 design load factors
- FAR 121 applicable sections
- BCAR emergency alighting conditions
- Improved seat safety standard; final rule
- Analytically developed crash design envelopes

The three contemporary fuselage fuel tank arrangements were examined with regard to their crash resistant features, design philosophies, and installation concepts. Program KRASH was used to facilitate an evaluation of the performance of fuselage mounted fuel tanks subjected to dynamic loads. For impacts in the airplane vertical direction 12 cases involving double wall cylindrical tanks were run, including 120-inch sections, 300-inch segments, and full-airplanes. These cases and their results are summarized in tables 3-1 through 3-3. Of interest were floor and fuel tank accelerations, fuel tank attachment loads, floor and/or airplane failure loads, and fuselage crush. The effect of attachment stiffness and mass on the responses were also investigated. For the situation in which a double-wall cylindrical tank installation is subjected to a longitudinal pulse another 9 KRASH runs were made. The results of these runs are presented in table 3-4.

Conformable tanks with bladders in a dedicated structured box is the type of configuration in use in many current narrow-body and wide-body airplanes. This type of tank can be supported from both the passenger and cargo floors and lower fuselage frames although the trend is toward passenger floor support only. The analysis results for the double-wall cylindrical tank were interpreted for this type of configuration for the following attachment arrangements:

- Passenger floor supported tanks
- Cargo floor mounted tanks
- Combined passenger and cargo floor attachments

The model parameters results of the analysis with conformable tanks is shown in tables 3-5 and 3-6, respectively.

A bladder fuel cell fitted in the wing center section is the most prevalent type of a fuselage fuel tank installation. Maximum utilization of available volume is achieved by conforming a bladder cell to the fuselage contour. A wing center section representation from a previous auxiliary fuel tank analysis was modified to eliminate the fuel tanks, but to consider the mass of the fuel as part of the structure. A center section weighing 47,050 pounds was analyzed for a 25 ft./sec. vertical impact velocity and the results showed an average floor peak acceleration of 12.5 g and an average crush of 8.4 inches. These results compared favorably to the 'Laurinburg' test and the post-CID parametric study results presented in reference 2.

Two test conditions are proposed to represent conditions that best meet crash design criteria developed in the parametric study described in reference 2, and to take into consideration previous test results, as well as recognize realistic structures and tests that can be run. Table 4-1 shows a comparison of proposed crash design criteria, previous section tests results, and the results of the analysis which may be most appropriate for producing either vertical or longitudinal loads. The suggested tests are as follows:

TABLE 4-1. COMPARISON OF TEST OR IMPACT CONDITIONS

FLOOR RESPONSES	PROPOSED CRASH DESIGN CRITERIA (REF. 2)	PREVIOUS FRAME SECTION TESTING (REF. 9 & 11)	ANALYSES		
			CASE NO. 1 TABLE 3-1 FRAME SECTION	CASE NO. 5 TABLE 3-4 SECTION FULL AIRPLANE	CASE NO. 5 TABLE 3-1 MODIFIED SECTION 3-3, CENTER SECTION
<u>VERTICAL DIRECTION</u>					
Velocity Change, ft./sec.	25	20	25	NA	25
Rise Time to Peak, sec.	0.075	0.06-0.08	0.075	NA	0.062
Peak Acceleration, g	10.4	8-10	7	NA	12.5
Crush Distance, in.					
Frame	16	16-20	24	NA	NA
Center Section	10	NA	NA	NA	8.4
<u>LONGITUDINAL DIRECTION</u>					
Velocity Change, ft./sec.	30	36.2	NA	40	NA
Rise Time to Peak, sec.	0.09	0.07	NA	0.100	NA
Peak Acceleration, g	10.2	14.7	NA	10	NA
<u>SECTION SIZE & WEIGHT</u>					
Size, in.	NA	120	120	120	200
Weight, lb.	NA	6,000-8,500	13,690	208,000	47,050

NA = Not Applicable

1. Vertical Impact

- Frame fuselage section length: 120 inches
- Impact Velocity of: 20 - 25 ft./sec.
- Rise time to peak: 0.075 seconds *
- Peak acceleration: Floor of 8 - 10 g *
- Weight: 8500 - 10,000 pounds
- Fuel tank configuration: One double-walled cylindrical tank, passenger floor mounted

  * Parameters resulting from impact velocity

Case No. 1 shown in table 3-1 analyzed a 25 ft./sec. impact. The weight was 13,690 pounds which is considered high. The analysis included two tanks. Eliminating one tank reduces the analytical model to a 9,290 pound representation. Testing at 20 ft./sec. has the advantage of:

a) Comparing results with several previous 20 ft./sec. drop tests and

b) Reducing the crush to a more desirable 16 inches. The latter crush is more representative of the levels anticipated with a full airplane. However, the velocity change and resulting acceleration levels need to be compromised to achieve the appropriate crush level.

2. Longitudinal Impact

- Frame fuselage section length: 120 inches
- Impact velocity: 30 - 36 ft./sec.
- Rise time to peak: 0.07 - 0.10 sec.
- Peak acceleration: 10 - 14 g
- Specimen weight: 8500 - 10,000 pounds
- Fuel tank configuration: One double-wall cylindrical tank, passenger floor mounted

Case No. 9, shown in table 3-4, represents a simulation of a section exposed to an induced 36 ft./sec. 14.2 g pulse. Case No. 5, also from table 3-4, depicts the response from an airplane impact into a rigid wall to produce acceleration response to a 40 ft./sec. velocity change. The overall vehicle and fuel tank responses for this latter analysis are lower than the values

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* Anticipated result from the impact velocity

obtained from the case no. 9 simulation. However, a previous test has been performed with a longitudinal pulse, as described above, for a 5,792 pound section without fuel tanks (reference 4). The performance of a test under a matching impact condition has the advantage of being able to compare to some existing data.

A test with a specified impact velocity of a more complete segment or airplane with hard points, with the expressed desire to produce a well defined floor pulse, is not realistic.

The objectives of a test program should be multifaceted and include the following:

- Determine the dynamic response behavior of a fuselage mounted auxiliary fuel tank installations in a narrow-body airframe when subjected to:

  a. longitudinal pulse
  b. vertical pulse

- Obtain test data to compare with analysis results and improve prediction methodology.

- Determine if the need exists for crash resistant design features for a current fuselage auxiliary installation.

- Determine if the current installation procedures for fuselage auxiliary fuel systems are adequate.

- Determine the extent of the need for additional test configurations and conditions.

A potential test program involving different types of fuselage fuel tank installations of the type investigated is provided in table 4-2 and the associated flow diagram is shown in figure 4-1.

A preliminary test program is presented in Appendix A which describes two tests: a longitudinal pulse excitation test and a vertical impact test. The premises, objectives, test facilities and specimen test parameters, instrumentation, and documentation are outlined.

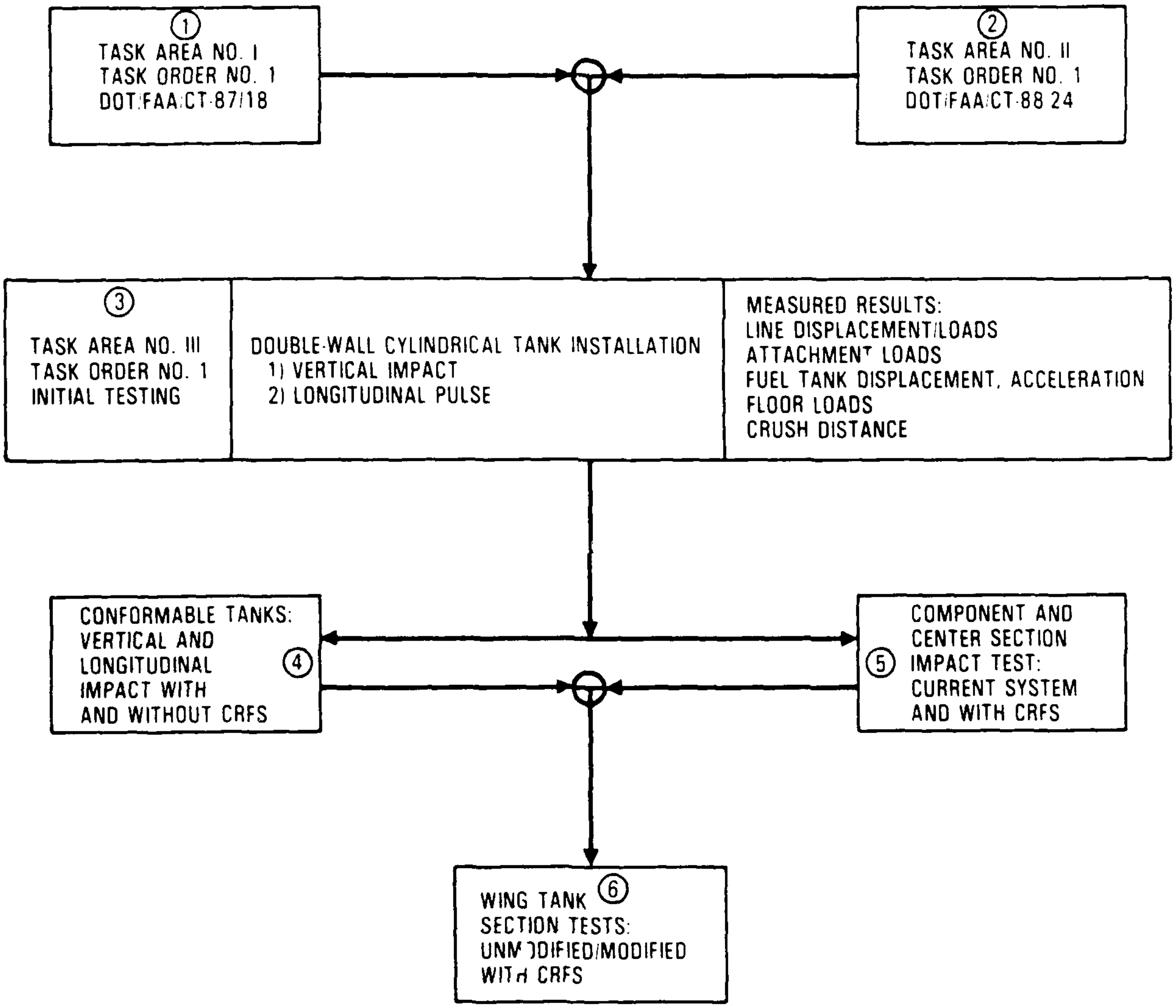

Figure 4-1. Potential Fuel Tank Installation Test Flow Diagram

TABLE 4-2. POTENTIAL TEST PROGRAM-FUEL CONTAINMENT

TASK AND STATUS	DESCRIPTION
1. Task Area No. I, Task Order No. 1 DOT/FAA/CT-87/18, Nov. 1987 "Fuel Containment Concepts – Transport Category Airplane (Completed)	Initial four phase study to identify potential fuel containment concepts for transport category aircraft. A priority ranking and selection of approaches is made. Recommended the initiation of a short term test program for fuselage fuel containment and a long range program for wing fuel containment.
2. Task Area No. II, Task Order No. 1 DOT/FAA/CT 88/24, July 1989 "Investigation of Transport Airplane Fuselage Fuel Tank Installations Under Crash Conditions" (Completed)	Follow-on to Task Area No. I effort. Investigated three contemporary fuel tank installation configurations. Analyzed the installations under crash impact conditions with the aid of Program Krash. Recommended several potential test starting with two crash test conditions utilizing one of the contemporary installations.
3. Task Area No. III, Task Order No. 1 "Double-Wall Cylindrical Fuselage Auxiliary Tank Installation Tests" (In Progress)	Two tests using a double-wall cylindrical tank installation. One test representative of a longitudinal pulse using the same set-up of a previously performed section test for passenger seat evaluation. The second test, a vertical impact similar to several previously performed FAA tests of seat/occupant installations. The purpose of the tests is to obtain dynamic responses and measured loads, accelerations and displacements and assess the need for CRFS and installation requirements (e.g., clearance, displacement, accelerations). Tests are to evaluate structural system responses and include frangible fittings.
4. Task Area No. III, Task Order No. 2 "Fuselage Auxiliary Conformable Tank Installation Tests" (In Planning Stage)	Test conformable tank installations under dynamic impact conditions similar to those in the previous phase. Installations can be passenger floor mounted, passenger and cargo floor mounted, or passenger and fuselage frame mounted. Purpose is to: • Obtain similar data to compare to double-wall tanks installations • Assess load transfer • Determine critical installations • Determine displacement requirements • Determine appropriate dynamic test requirements • Evaluate component test requirements Test with and without crash resistant features such as frangible fittings, self sealing lines and/or penetration resistant bladders. Testing at this level can require additional component tests and development. Loads, line displacement and crush performance are important parameters to evaluate. Could require additional component testing prior to section impact tests.

TABLE 4-2. POTENTIAL TEST PROGRAM-FUEL CONTAINMENT (Continued)

TASK AND STATUS	DESCRIPTION
5. Task Area No. 3, Task Order No. 3 "Fuselage Wing Center Section Fuel Tank/Cell Installation Tests" (Future)	Test fuselage wing center section fuel cells with current bladders and with improved resistant materials. Tests of this nature require realistic loading to provide meaningful data. Section loadings to include affect of wing fuel mass on crushing of this section. Requires additional analysis to develop optimum test condition.
6. Task Area No. 3, Task Order No. 4 "Wing Fuel Tank Modifications and Tests" (Future)	Long range goal to evaluate wing fuel containment. Initial area of interest is inboard tanks near wing root. Concern is for penetration of forward structure and wing bending loads. Crash resistant features from previous fuselage tests should be used as initial indication of potential approaches. Requires supporting analysis and design considerations.

SECTION 5

CONCLUSIONS

1. The analyses results for a variety of fuselage auxiliary fuel tank installations and range of impact conditions show that the acceleration and load response characteristics are sensitive to:

• excitation and test configuration	(induced pulse shape versus prescribed free-fall impact velocity)
• fuel tank installation	(mount stiffness and attachment locations)
• loading and structure representation	(segment versus airplane, hard versus soft structure, loading density)

2. There is no one optimal test that can be performed. However, to assess the performance of fuselage auxiliary fuel tank installations in a dynamic environment, the analysis results indicate that two types of section tests be performed.

   a. Longitudinal-direction pulse in the range of 10 to 14 g peak acceleration and 30 to 36 ft./sec. velocity change.

   b. Vertical impact in the range of up to 25 ft./sec. velocity change inducing a floor response of 8 to 10 g and a crush ~ 20 inches.

3. A series of tests are needed to evaluate fuel tank installations and crash resistant fuel system (CRFS) components. Such a series of tests are outlined in table 4-2 and figure 4-1.

4. A preliminary test plan showing a typical installation and stating purpose/objective is provided in Appendix A.

SECTION 6

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APPENDIX A

PRELIMINARY TEST PLAN

A.1 TEST OBJECTIVES

The objectives of the test program are as follows:

- Determine the dynamic response behavior of a fuselage mounted auxiliary fuel tank installation in a narrow-body airframe when subjected to a:
  - Longitudinal pulse
  - Vertical pulse
- Obtain test data to compare with analytical results and improve prediction methodology.
- Determine if the need exists for crash resistant design features for a current fuselage auxiliary installation.
- Determine potential failure modes under dynamic impact conditions.
- Determine the extent of the need for additional test configurations and conditions.

Two tests will be performed. Both tests will involve the installation of a double wall cylindrical tank installed in a B707 section in its normal manner. One test will reproduce a section subjected to a longitudinal pulse, while the second test will represent a frame section subjected to a vertical impact.

A.2 PRELIMINARY TESTS

Prior to the two planned tests, several preliminary tests are to be performed. These tests include:

- Calibration of fuel tank attachment loads

  1. Fill the 330-gallon auxiliary fuel tank approximately 75 percent full with water (8.3 pound/gallon).

2. Attach strain gages on each of the fuel tank forward and rear cradles attachment legs to the floor support structure and on the tank straps, as noted in Figure A-1.

3. Attach fuel tank and cradles to the support structure.

4. Pull in the longitudinal (fore-aft) direction at the fuel tank installation up to a maximum of 6 g ($\approx$14730 pounds). Record load versus strain (deflection).

- Pre-test longitudinal direction.

  1. Install auxiliary fuel tank in the airframe section.

  2. Ensure that all instrumentation is in place.

  3. Perform a longitudinal impact (pulse) test with a low energy pulse ($\leq$6 g, Δv<25 ft./sec.) with a 0.080 second rise time.

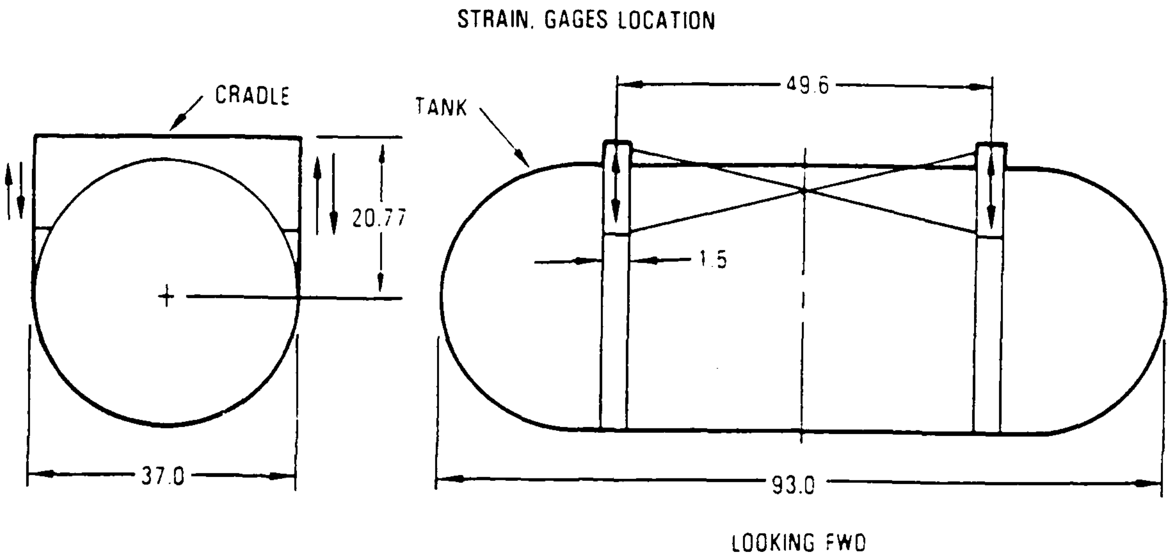
  4. Record the following:

     - Pulse magnitude and shape
     - All instrumentation channels
     - High speed motion pictures

  5. Check floor beams, tank intercostals, clearances, and plumbing integrity and leakage.

A.3 LONGITUDINAL IMPACT TEST

The test will be performed at a facility which contains an impact simulator device (such as 24 inch diameter Hyge sled system) or equivalent. The B707 test article shall be rigidly mounted to a support fixture and drive sled system. The required test shall be represented by the sled and supported test section being accelerated by the impact simulator device to a defined impact simulated condition, as depicted in figure A-2. The sled mounted support fixture shall be designed to support the weight of the test section and installed systems. It must also be designed to withstand both acceleration and deceleration forces, including overturning moments resulting from the test impact conditions as defined in Subsection A.3.1. Attachment locations between the fixture and section shall not interfere with the load path and generated loads measured at the floor and/or sidewall structure during the test.



WEIGHTS	POUNDS
OTHER:	94
TANK:	242
FUEL:	2055*
CRADLE ASSY:	54
	2455

*BASED ON 75 PERCENT FULL WITH WATER (8.3 POUND/GALLON)

OTHER WTS:		POUNDS
	LINES	17
	INTERCOSTAL	52
	MISC	25
		94

Figure A-1. 330-Gallon Cylindrical Tank Size

A.3.1 Impact Test Parameters

The test shall be conducted with the impact simulator device accelerating the sled fixture and attached fuselage test section at the required simulated impact condition. The test envelope condition is defined as follows:

• Sled pulse shape:	Triangular
• Sled velocity:	33 ft./sec. ±3
• Sled peak acceleration:	10 g +4/-0
• Sled pulse duration:	0.160 msec with peak acceleration at no more than 80 msec. after impact

Perform post-test inspections as noted previously.

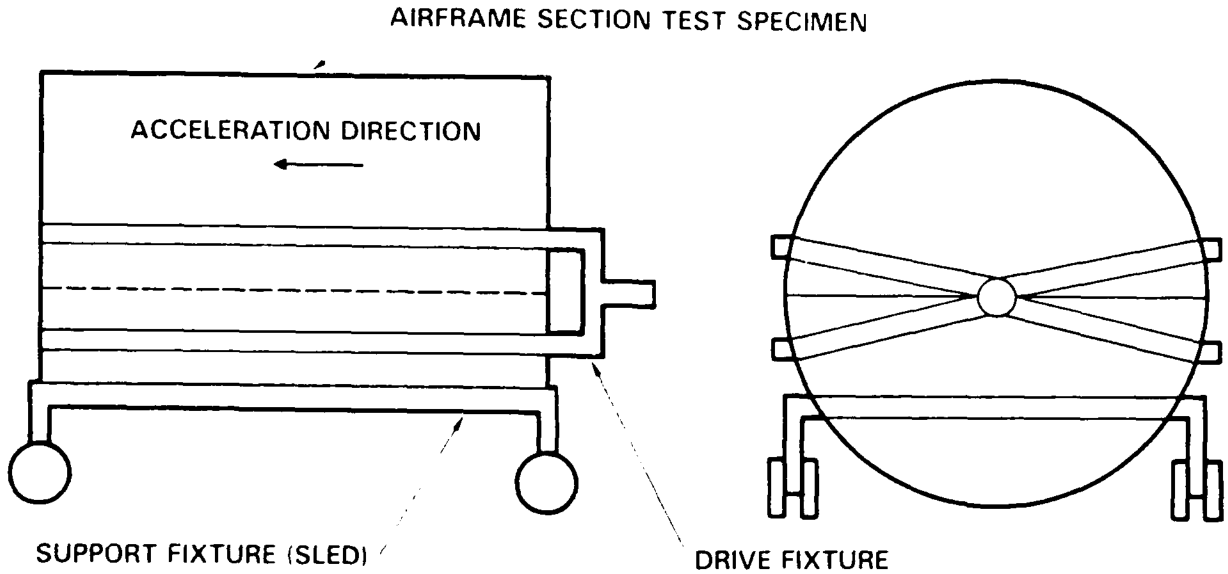


Figure A-2. Drive/Support Fixture for Longitudinal Impact Test

A.3.2 Longitudinal Impact Test Article/Installed System

The aircraft test article shall consist of a 10-foot B-707 fuselage section (Body Station (BS) 1120 - BS 1240) with onboard dummy/seat systems and an auxiliary fuel tank installation (figure A-3). The outer floor beams at each end of the section shall be reinforced to minimize the open end effects. Also, the section interior shall be stripped of liner material and exposed structure checked for damage prior to the installation of onboard systems. The seats, as represented by six (6) floor mounted triple passenger type designs, shall be installed in three rows within the fuselage cabin section. Seat pitch dimensions shall be maintained at 30 inches or greater. Seat leg spacing shall be recorded. The seats will be similar to those described in a previous longitudinal impact test which is described in reference 12. Each of the seat designs will have been tested and calibrated previously at the intended test pulse. Static and dynamic calibration of the seat designs will have been conducted at FAA (CAMI) test facilities utilizing a strain gaged leg

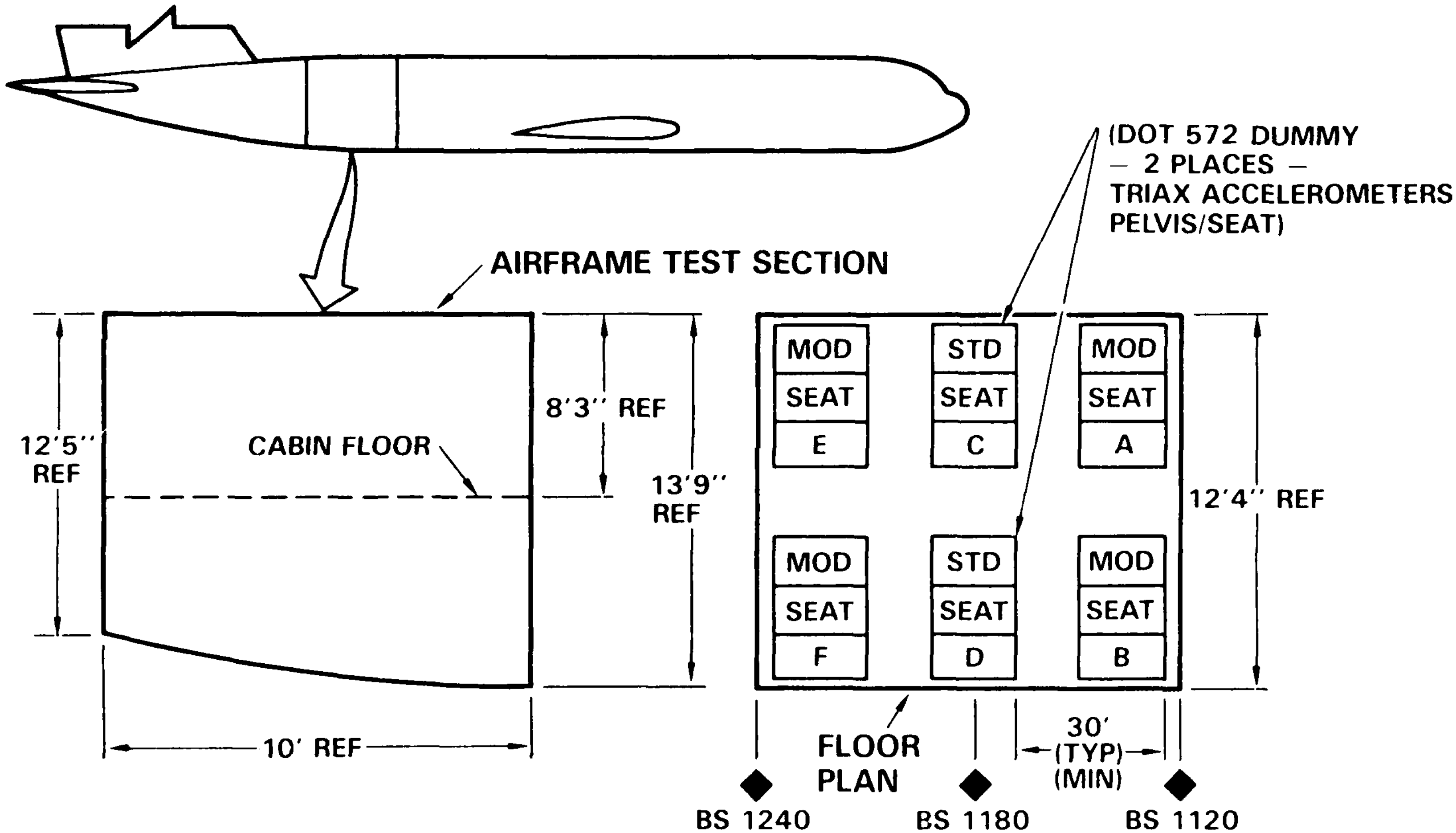


Figure A-3. Airframe Test Section - Longitudinal Impact Test

structure and leg load cell support mount installation. With their primary purpose of loading the seat and floor structure, a total of eighteen 50th percentile adult male dummies shall be used in the test. The dummies shall be belted with seat belts having sufficient strength to restrain the dummies under the intended impact loads. Two of the dummies (located in the middle position of each center row seat) shall be calibrated DOT 572 (Hybrid II) anthropomorphic type, which contain pelvis triaxial accelerometers (head accelerometers may be added).

The auxiliary fuel tank shall be a 330-gallon double wall cylindrical configuration (figure A-3) and mounted as shown in figure A-4. The tank shall be installed between BS 110 and BS 1180, depending on clearance and fixturing requirements. The floor attachment intercostals will be reinforced. Details of the reinforcement will be provided in the finalized test plan.

Estimated weights of the fuselage test section, fuel tank installation, seats and dummies are as follows:

• Auxiliary fuel tank installation	-	2,455
• Fuselage section	-	2,286
• Seats	-	506
• Dummies	-	3,060
TOTAL		8,307 pounds

A.4 VERTICAL IMPACT TEST

The test will be performed at the FAA Technical Center in Atlantic City, N.J., using the existing drop tower. The B707 test article shall be hoisted to an appropriate height consistent with the desired impact speed. The required test shall be represented by the section including dummies and fuel tank impacting the ground with a prescribed vertical sink or impact velocity, as shown in figure A-5. The general test arrangement and sensor locations are shown in figure A-6.

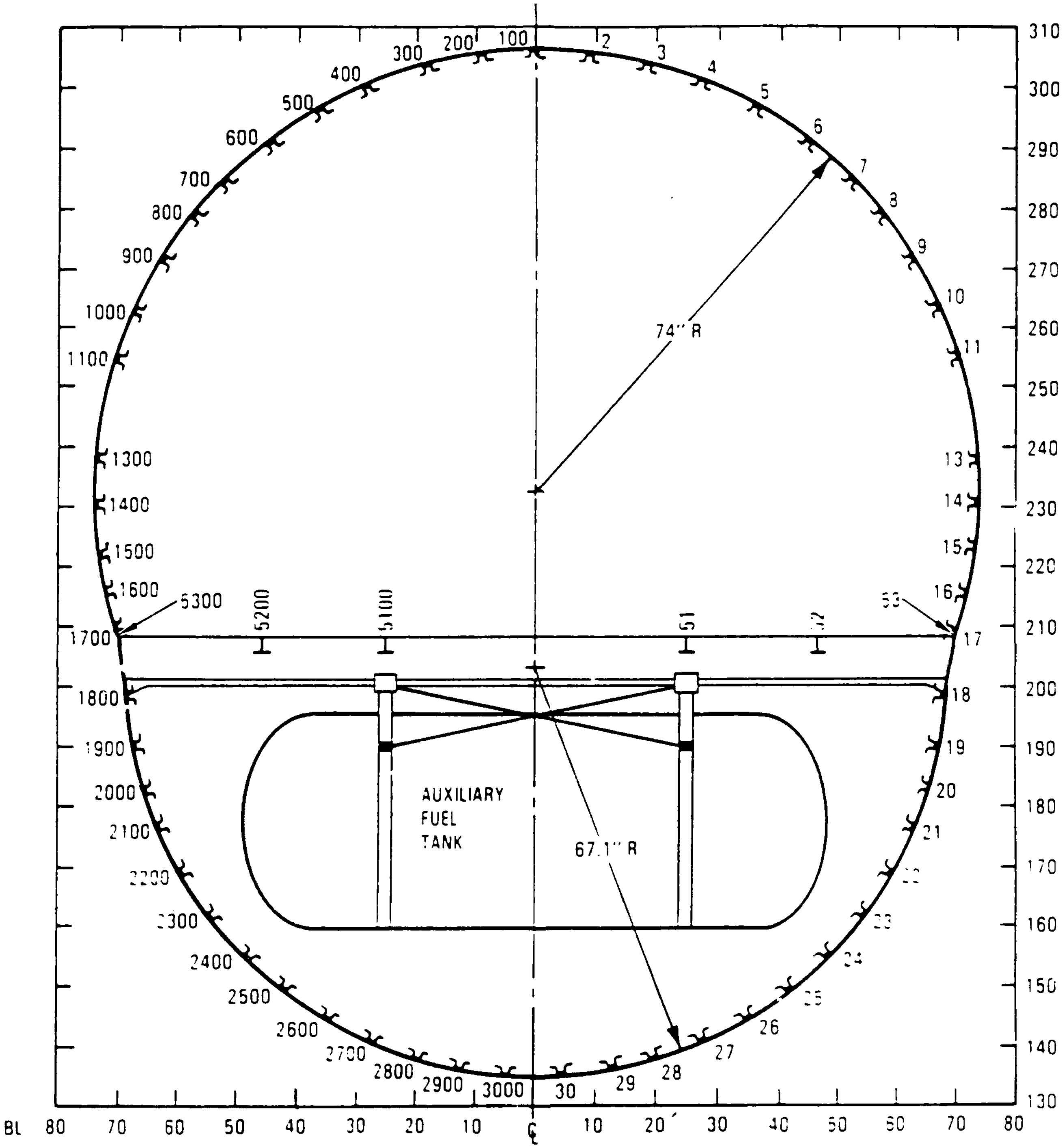


Figure A-4. Typical Cross-Section with 330-Gallon Auxiliary Fuel Tank Installation

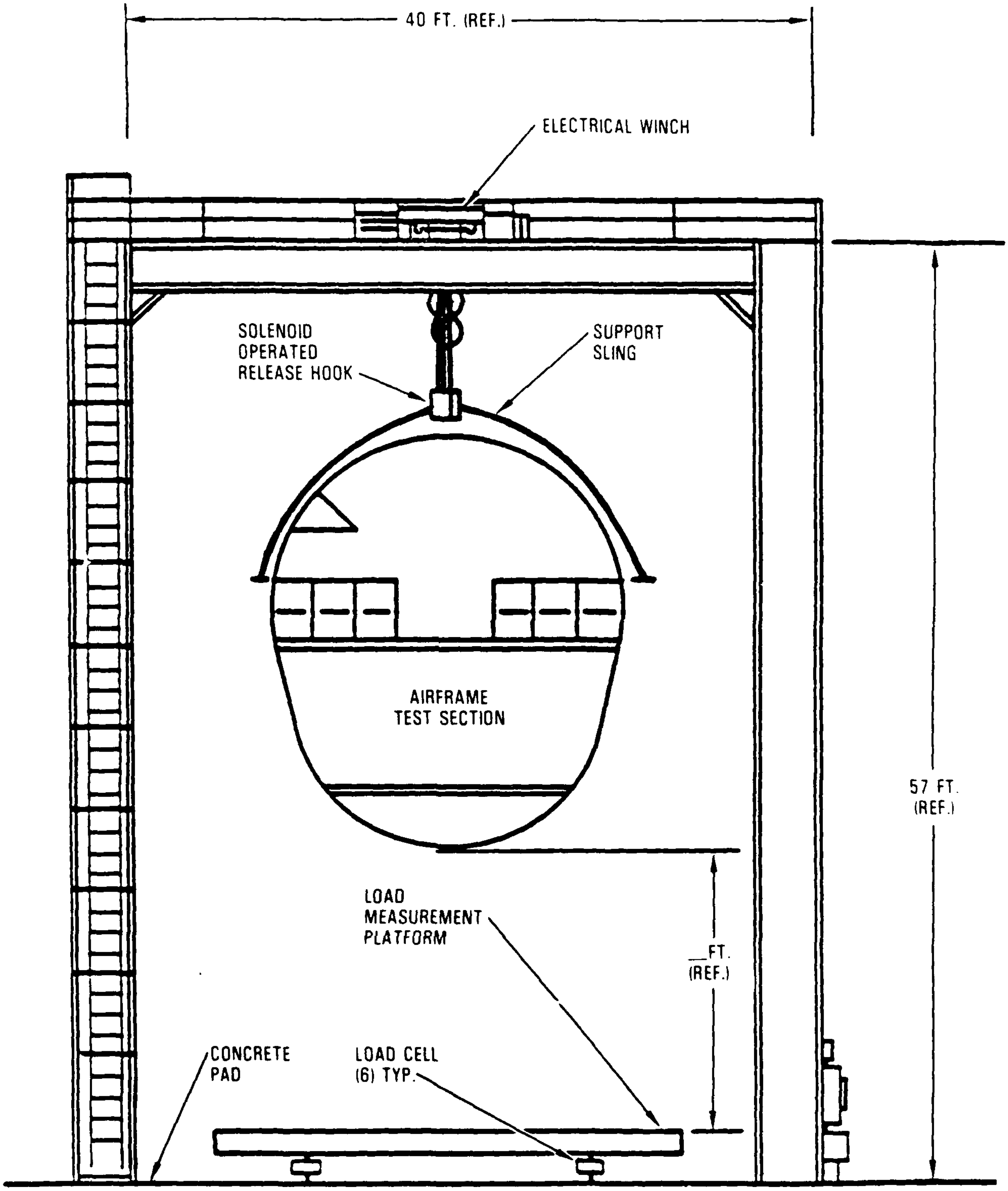


Figure A-5. Drop Test Facility

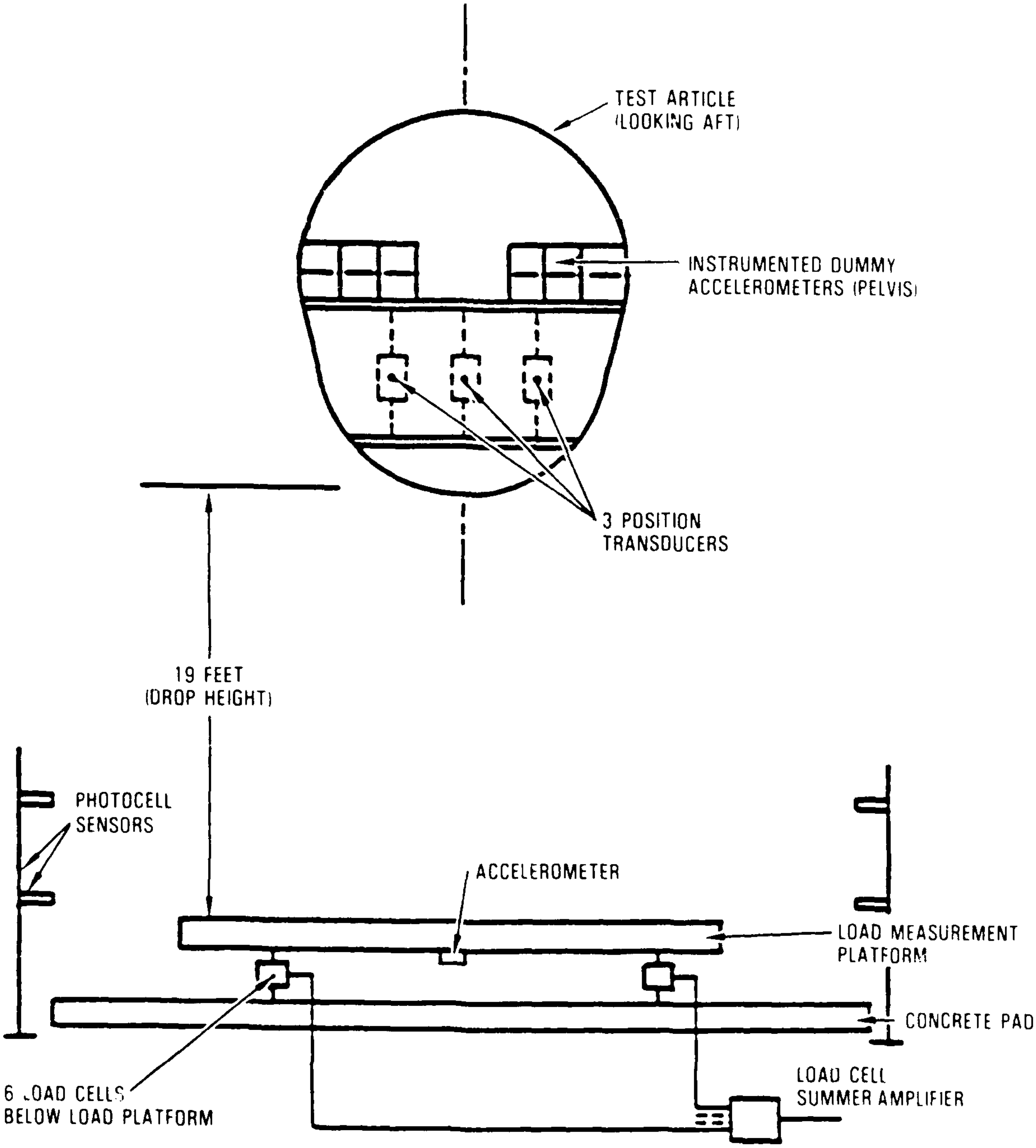


Figure A-6. Test Arrangement and Sensor Locations

A.4.1 Test Parameters

The test shall be conducted with the section including dummies and fuel tank impacting the ground as a result of a free-fall condition. The test impact condition is to produce a vertical impact velocity of 20 ft./sec.

A.4.2 Test Article/Installed System

The aircraft test article shall consist of a 10 foot B-707 fuselage section (Body Station (BS) 1120 - BS 1240) with onboard dummy/seat systems and an auxiliary fuel tank installation as shown previously in figures A-2 and A-3, respectively. The outer floor beams at each end of the section shall be reinforced in the same manner as prescribed for the longitudinal test. The seat and fuel tanks installation will be identical to those described for the longitudinal impact test. The estimated weight of the fuselage test section, fuel tank installation, seats and dummies are as follows:

• Auxiliary fuel tank installation*	-	2,455
• Fuselage section	-	2,286
• Seats	-	506
• Dummies	-	3,060
TOTAL		8,307 pounds

* Includes 330-gallon fuel tank, 75 percent full with water

A.5 INSTRUMENTATION

A.5.1 Longitudinal Impact Test

As identified under table A-1 and in figure A-7, instrumentation shall consist of a series of accelerometers, strain gages and other measurement devices. The instrumentation shall be installed on the airframe structure, floor structure, fuel tank and its attachments, and seat/dummy/restraint system locations. In addition, high-speed camera coverage (500-1000 frames per second) shall be provided both within and external to the fuselage test section. Five onboard cameras and up to three offboard cameras shall be

positioned at selected areas. An approximate placement of the onboard cameras is shown in figure A-8. The exact location of cameras (and coverage area) shall be identified and approved by FAA program manager prior to the test.

A.5.2 Vertical Impact Test

The instrumentation for the vertical impact test is identified in table A-2 and figures A-9, A-10, and A-11. The instrumentation consists of a series of accelerometers, strain gages, load cells, and other measurement devices. The instrumentation shall be installed on the airframe structures, floor structure, fuel tank and its attachments, and seat/dummy/restraint system locations. In addition, high-speed camera coverage (500-1000 frames per second) shall be provided both within and external to the fuselage test section. Four onboard cameras and at least three off-board cameras shall be positioned at selected areas. An approximate placement of the onboard cameras is shown in figure A-12. The exact location of cameras (and coverage area) shall be identified and approved by the FAA program manager prior to the test.

A.6 DOCUMENTATION

Documentation shall provide for a complete part number identification of test article, included structural components and onboard systems. Documented results shall include a presentation of measured instrumented data obtained during the simulated impact test. Photographic coverage (before and after) shall also be provided in the form of 35mm still pictures, high-speed photography (as previously discussed, plus overall external views) and video. Particular attention shall be given to measured response load variations (if any) between basic airframe section and cabin floor. Loads, deformation, and peak and average accelerations, associated with the impact, shall be presented.

TABLE A-1. LONGITUDINAL TEST INSTRUMENTATION

	ACCELEROMETER			STRAIN GAGE	LOAD CELL	STRING POT.	CRACK DETECT	"PRESSURE SENSORS"	NO.
	LONG.	LAT.	VERT.						
FUSELAGE	3	–	–	–	–	–	–	–	3
FLOOR	4	3	3	4	–	4	5	–	23
SEATS	2	2	2	14	–	–	–	–	20
SEAT BELTS	–	–	–	--	4	–	–	–	4
DUMMIES* (PELVIS)	2	–	2	–	–	–	–	–	4
SLED	2	–	–	–	–	–	–	–	2
FUEL TANK	4	–	4	–	–	–	–	–	8
FUEL TANK MOUNTS	–	–	–	8	–	–	–	–	8
FUEL TANK	–	–	–	–	–	–	–	2	2
TOTAL									74

*NOTE: HEAD-MOUNTED ACCELEROMETERS MAY BE INSTALLED IF INSTRUMENTATION CHANNELS ARE AVAILABLE

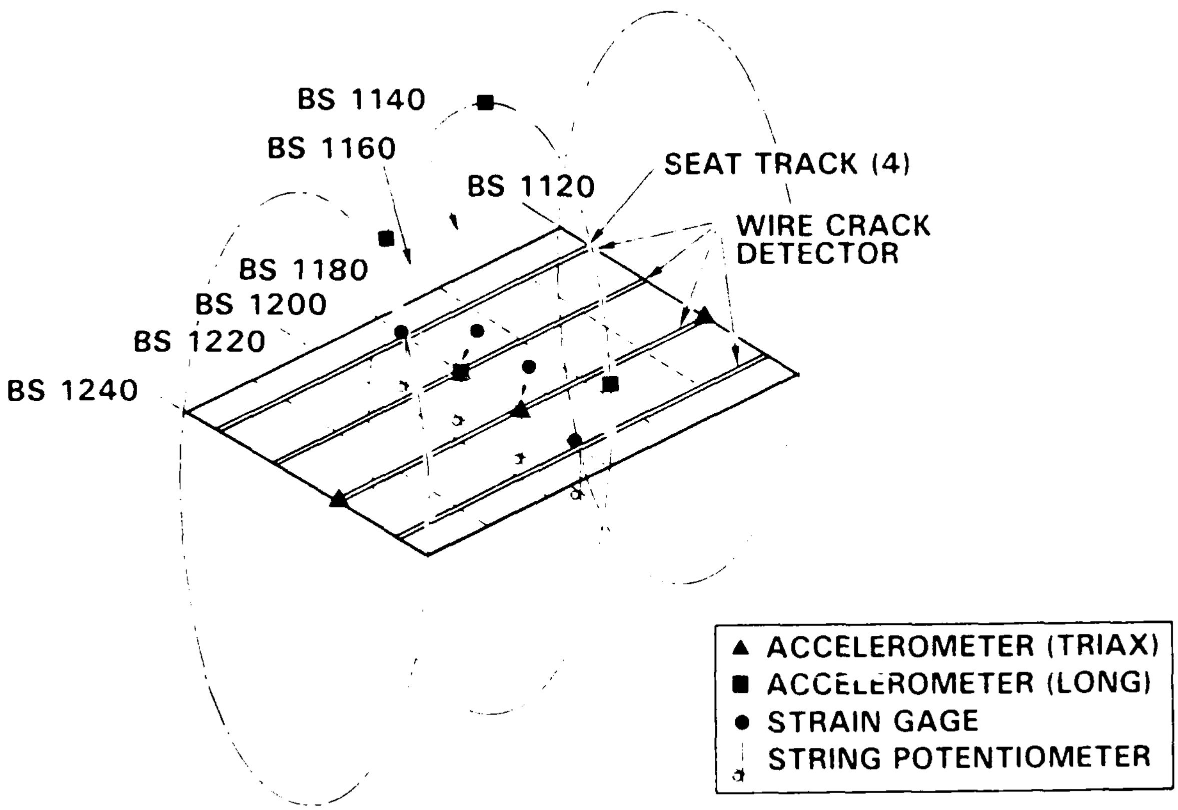
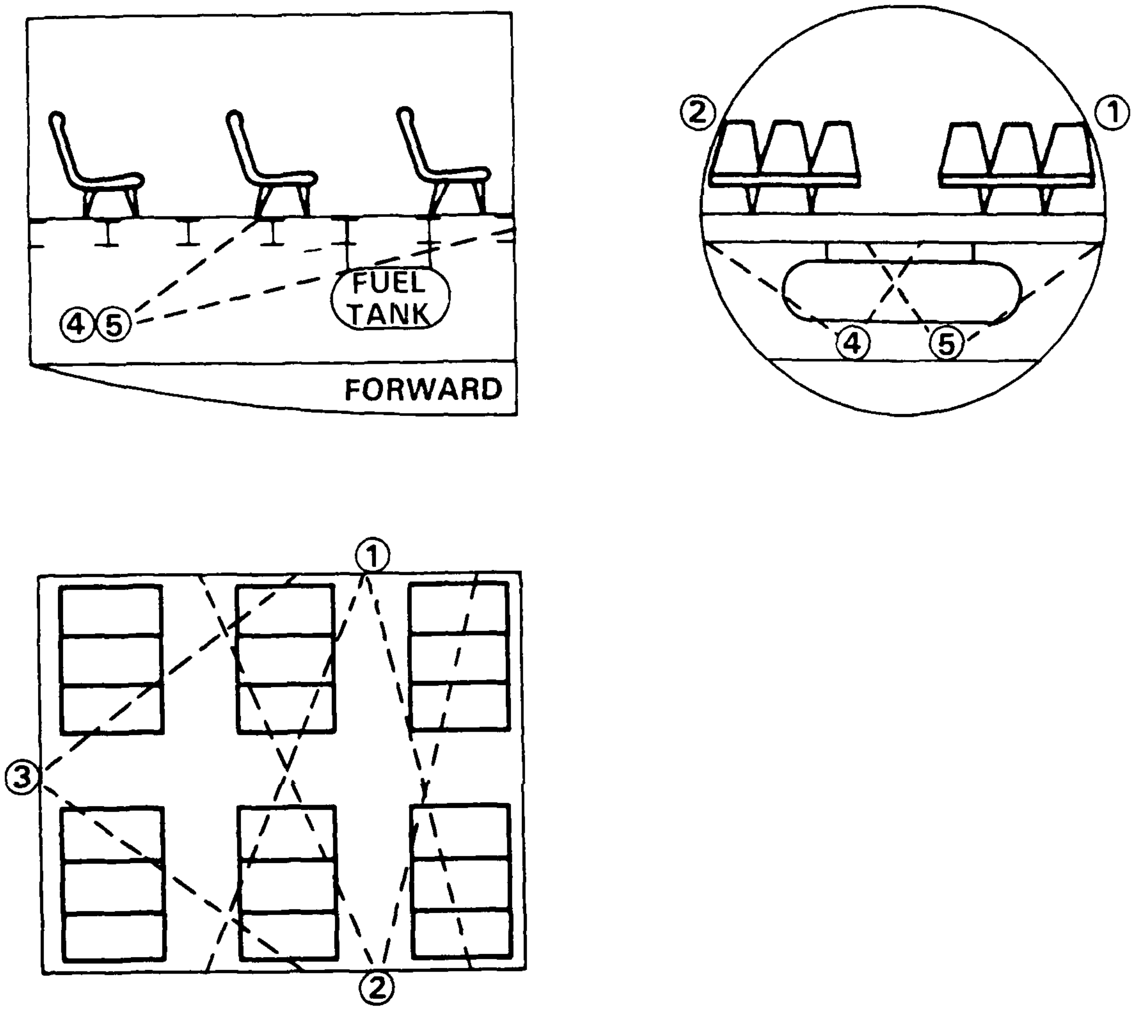


Figure A-7. Floor and Airframe Instrumentation Locations



① CENTER ROW SEAT DUMMY — STARBOARD (THROUGH WINDOW)

② CENTER ROW SEAT DUMMY — PORT (THROUGH WINDOW)

③ CABIN FLOOR UNDERSIDE — CENTER AND AUXILIARY FUEL TANK ATTACHMENTS

④ UNDERSIDE FLOOR BEAMS — STARBOARD AND AUXILIARY FUEL TANK ATTACHMENTS

⑤ UNDERSIDE FLOOR BEAMS — PORT AND AUXILIARY FUEL TANK ATTACHMENTS

Figure A-8. Onboard Camera Location - Longitudinal Test

TABLE A-2. VERTICAL TEST INSTRUMENTATION

	ACCELEROMETER			STRAIN GAGE	LOAD CELL	STRING POT.	CRACK DETECT	"PRESSURE SENSORS"	NO.
	LONG.	LAT.	VERT.						
FUSELAGE	4	2	4	–	–	–	–	–	10
FLOOR	12	6	12	–	–	4	5	–	39
SEATS	2	2	2	14	–	–	–	–	20
SEAT BELTS	–	–	–	–	4	–	–	–	4
DUMMIES* (PELVIS)	2	–	2	–	–	–	–	–	4
FUEL TANK	4	2	4	–	–	–	–	–	10
FUEL TANK MOUNTS	–	–	–	8	–	–	–	–	8
FUEL TANK	–	–	–	–	–	–	–	2	2
TOTAL									97

*NOTE: HEAD-MOUNTED ACCELEROMETERS MAY BE INSTALLED IF INSTRUMENTATION CHANNELS ARE AVAILABLE

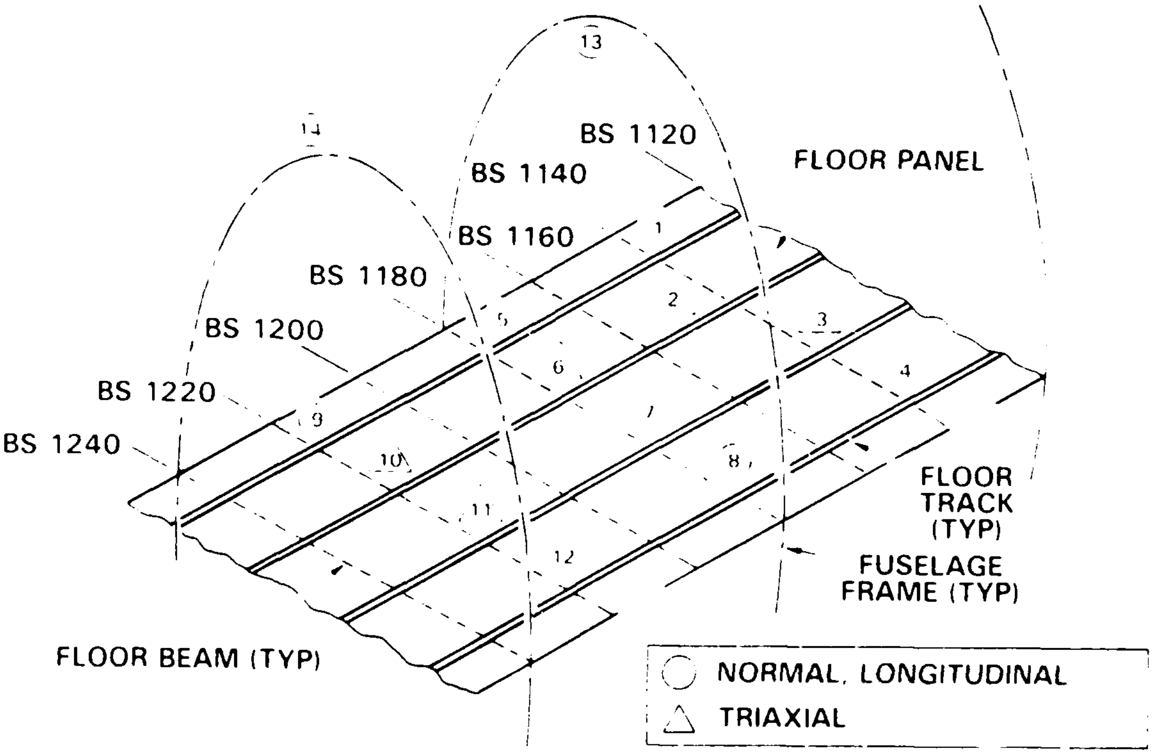


Figure A-9. Floor and Airframe Instrumentation of Airframe Structure - Vertical Impact

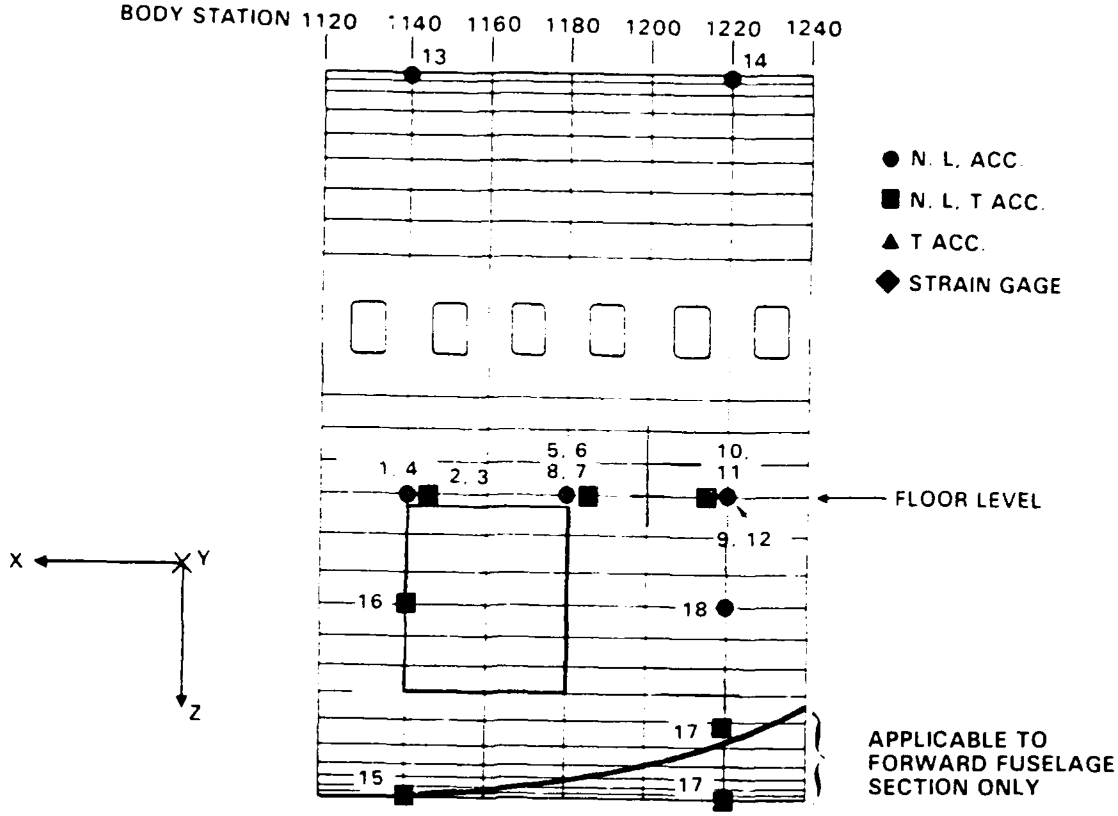


Figure A-10. Side View of Floor and Airframe Instrumentation - Vertical Impact

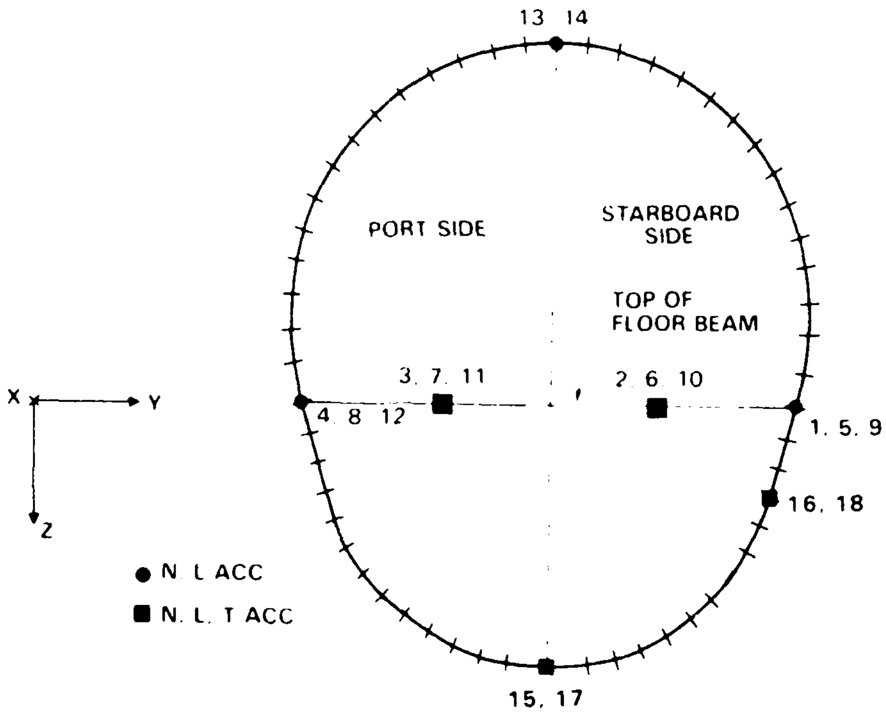
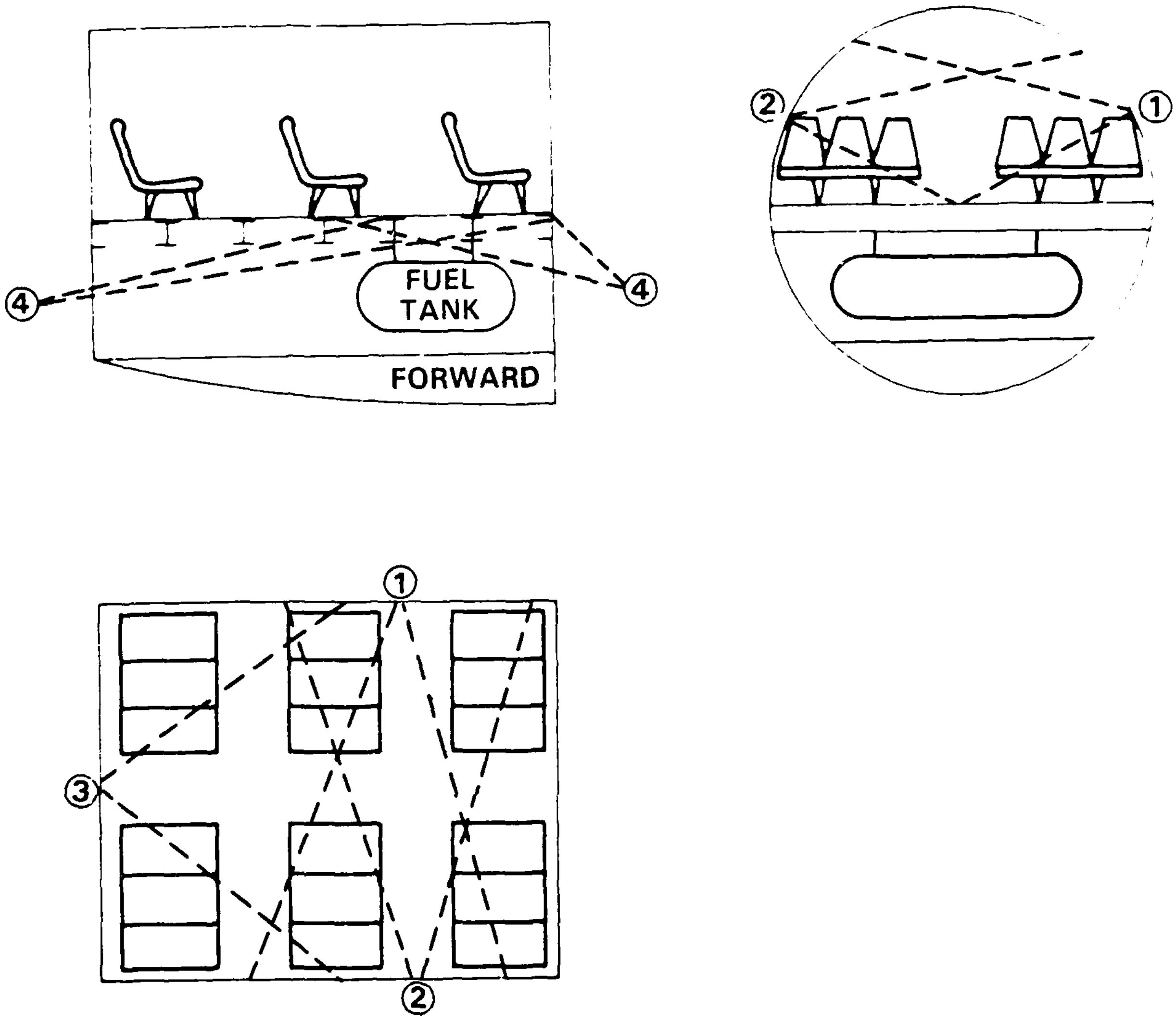


Figure A-11. End View of Floor and Airframe Instrumentation - Vertical Impact



① CENTER ROW SEAT DUMMY — STARBOARD (THROUGH WINDOW)

② CENTER ROW SEAT DUMMY — PORT (THROUGH WINDOW)

③ CABIN FLOOR UNDERSIDE FWD — TO VIEW FUSELAGE FUEL TANK ATTACHMENTS

④ CABIN FLOOR BEAMS UNDERSIDE AFT — TO VIEW FUSELAGE FUEL TANK ATTACHMENTS

Figure A-12. Onboard Camera Location - Vertical Test